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Guidelines for Hosted Payload Integration

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Abstract and Executive Summary

Hosted Payloads are installed on Host Space Vehicles with available capacity; this approach is an efficient use of resources and reduces the time for successful orbital operation of the Hosted Payload. The “do no harm analysis” effort has traditionally focused on an interface failure modes and effects analysis (FMEA) to verify that potential propagating failure modes in Hosted Payloads do not affect successful operation of the Hosted Space Vehicle’s primary mission. This FMEA focused on “single hard failures,” evaluated their interface failure effects on mission performance and verified that design mitigation was present to limit failure propagation and damage, or identified needed design changes to limit the effects of potential interface failure modes.

When development and delivery of the two design configurations are not synchronized, requirements and performance incompatibilities can pose potential risks to overall mission success. Contamination, electromagnetic interference (EMI), mechanical layout/integration and electrical interface design integration are areas of potential problems. Because of time pressures associated with meeting delivery milestones that satisfy launch dates, mistakes have been made on past programs and issues have been discovered late during the integration process. This results in schedule slips, engineering rework or both.

Key decision points, requiring constant communication, are graphically described in Section 3, showing Phases of Accommodation. Phasing of the two design configurations is discussed in Section 3.2, Accommodation Study and Gap Identification. A discussion of the gaps or potential incompatibilities resulting from early/late participation in the design process or early/late flight hardware deliveries for integration and system test is included. In some cases, a completed Hosted Payload design may be a candidate for integration into a Host Space Vehicle.

An integrated team of engineers from The Aerospace Corporation and contractors from across the United States worked as part of the Mission Assurance Improvement Workshop (MAIW) to share their lessons learned and develop guidelines in the form of checklists for improving the design integration process and likelihood of mission success. Lessons learned with descriptions of the issues, likely causes and corrective actions are summarized in a table. The checklists are included in Appendix A and include 14 areas of expertise, such as contamination control, optics, mechanical and electrical design integration. The need for critical analyses to ensure compatibility at the interfaces and effect on mission performance was also recognized. These analyses include failure propagation/fault tolerance, worst case circuit analysis, timing analysis and single events effects (SEE) analysis on both sides of the interface.

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Contents

Figures

Tables

1. Introduction

1.1 Hosted Payload Definitions and Terms

Independently developed payloads can enter service more economically using a hosted payload approach than by using a dedicated spacecraft and launch vehicle. A commercial operator or other entity can defray its own costs by providing hosted payload opportunities to an independently developed payload.

Recent hosted payload projects have met with success, achieving objectives that otherwise would not have been practical. However, some have also experienced avoidable problems in development, in test, and on orbit.

This document was compiled by a group selected from a cross-section of organizations in the space industry. This is the first industry-wide independent evaluation of Hosted Payload performance and guidelines. Its intent is to advise those implementing hosted payload projects, as either a host or as a hosted payload provider, to potential risks that should be considered.

It is intended primarily for those performing program management, systems engineering, design and mission assurance activities on both the host and payload side of the project. It will also be useful to any intermediary organizations that must manage information flow between the host and payload as part of a more extensive project.

1.1.1 Terms

The following terms and definitions used in this document are derived from those used in References 1 through 4 and other sources.

The ***Host***, in this document, refers to the team providing the ***Primary Mission***: the hosting spacecraft and its primary payload(s). The hosting spacecraft is designed, integrated, and tested by a ***Prime Contractor*** under contract to the ***Owner and Operator*** of the primary mission. Either the Prime Contractor or Owner will select the launch vehicle and provide launch services.

A ***Hosted Payload*** is a payload added to a spacecraft that is unrelated to the original mission(s). It typically uses excess spacecraft capacity to fulfill its mission objectives.

After delivery into orbit, the Hosted Payload will be operated as agreed between the Hosted Payload operator and the primary mission Owner/Operator. Planning how to operate the hosted payload on orbit is important for success of the mission.

Programmatic responsibility will vary from mission to mission. It should be carefully defined and agreed upon prior to commencement of the program. There will likely be participants beyond the provider of the hosted payload and the Host involved in interface activities, to help integrate and ensure proper operation of the Hosted Payload Space Segment. Examples of hosted payload development organizations are provided in References [1] and [2]. The material in this document will focus on the information and properties that should be coordinated between the Hosted Payload and the Host, since this is independent of the organizations through which necessary information passes.

For the remainder of this document, we will refer to the hosted payload as the ***Payload***. The payload(s) of the primary mission will be referred to as the ***Primary Payload***. The figure below

provides a generic picture of Host and Payload and their responsibilities. Hosted payload projects can have a much more complicated structure than the one shown here.

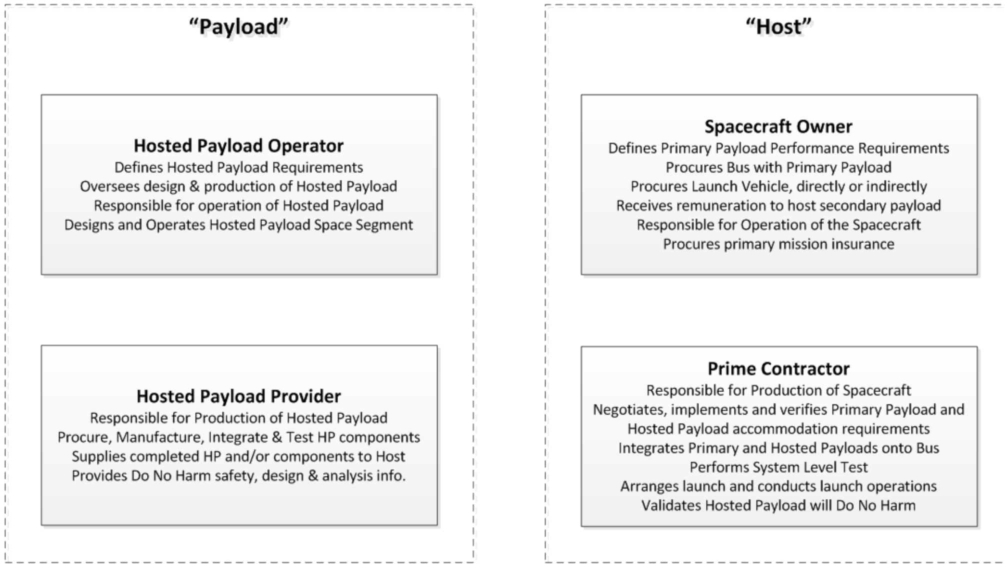

Figure 1. Sample payload and host organizations.

1.2 Historical Hosted Payload Challenges

This document is motivated by historical problems with hosted payload projects. Unforeseen schedule, technical, and operational compatibility issues have caused problems during integration, in test and on orbit for both Payloads and Hosts. Compatibility issues that are not identified and resolved in a timely manner can "cause harm" to both the Host and the Payload.

These issues can arise from unnoticed gaps between the requirements, capabilities, or configuration of the Host and Payload. These gaps are more frequent in hosted payload projects because the Payload and Host are usually developed independently, often without knowledge of environments, requirements, and capabilities on the other side of the interface.

Out-of-phase development, which is common between a Hosted Payload and the Host's Primary Mission, can be a major cause of gaps between capabilities and requirements. Gaps can also result from compartmentalization; use of previous designs that were qualified for different applications and from lack of communication, even in co-developed projects.

Timely sharing of key design information is mandatory, since design flexibility of the host and hosted payload will decrease significantly as the host and its primary mission mature.

The Payload provider may implement parts, units, or processes from outside vendors or US government sources. Payload provider nondisclosure agreements or security restrictions with these sources that exclude the Host should be avoided, since they may inhibit or significantly delay the Payload provider from sharing key interface information with the Host, hindering the design process and increasing risk.

Insufficient or inadequate analysis or test, perhaps resulting from these same causes, can also result in unanticipated incompatibilities.

1.3 Preventing Harm

Harm that a Payload can create at the system level can come from many sources, some of which might not be apparent to a hosted payload provider accustomed to building instruments or payloads rather than systems. Similar problems can arise from a host that is not sufficiently aware of the nuances of a specific Payload. Sample harm that can occur includes:

- Noise and offsets due to ground loops
- Coupling of Electrostatic Discharge
- Arcing due to partial pressure from inadequate venting
- Contamination of thermal and optical surfaces
- Glint and other field of view violations
- Ripple from antenna side lobes and other RF interference
- Use of more resources than allocated, or allocation of less resources than promised
- Noise, shorts or excessive loading on shared data buses
- Attitude disturbance or mechanical damage from moving or unsecured items
- Interlock configurations or spurious emissions that violate launch safety regulations
- Damage due to the launch dynamics environment

The checklists provided later in this document are intended to help spur the thought process during the initial phases of a payload project. They are based on the experiences of individuals in our group and of their companies. They do not provide a cookbook for hosting payloads, nor should they be considered a replacement for the Systems Engineering process that is required to appropriately host a payload.

The Host Should:

- Define interfaces early and maintain configuration control
- Budget and provide committed resources to the Payload
- Identify any faults that can propagate to the Payload so they may be appropriately mitigated
- Not have single faults that impede the Payload mission beyond agreed-upon provisions
- Not expose the Payload to damaging environments in normal or contingency operations

The Payload Should:

- Strictly adhere to interfaces negotiated with the Host
- Identify any unmitigated propagating faults so they may be mitigated by the Host
- Stay within agreed upon allocations, even in fault conditions
- Not impact the primary mission beyond agreed upon constraints

2. References

2.1 Reference Documents

Documents listed in Table 1 provide good references for, and examples of, interface, environment, and procedural requirements. They are called out in the body of this text as relevant.

2.2 Additional Reference Documents

Additional reference documents are provided in Appendix A, in support of the checklists located there.

Table 1. Table of Reference Documents

Ref	Document	Reference	Intent
1	Commercially Hosted Payload Implementation Policy	Goddard Interim Directive GID 7120.2	An example of organizational roles and responsibilities.
2	Hosted Payload Solutions Statement Of Work	FA8814-13-R-0001, 1 August 2013, Section 1.3	An example of organizational roles and responsibilities.
3	Hosted Payload Standard Interface Specification	HPSIS, Space and Missile Systems Center, Hosted Payload Office	An example hosted payload interface specification.
4	Hosted Payload Guidelines Document (Common Instrument Interface Requirements)	National Aeronautics and Space Administration Document CII-CI-0001, Rev A	An example hosted payload interface specification.
5	Criteria For Flight and Flight Support System Lifecycle Reviews	GSFC-STD-1001A	An example set of evaluation criteria that can be tailored to a specific program.
6	General Environmental Verification Standards (GEVS), for GSFC Flight Programs and Projects	NASA Goddard Space flight Center, GSFC-STD-7000, April 2005	A generic Environmental Requirements Document.
7	Test Requirements For Launch, Upper-Stage, & Space Vehicles	SMC-S-016	A generic Test Requirements Document.
8	NASA SE Handbook, Appendix L, IRD Outline	NASA SP-2007-6105	An example outline for an Interface Requirements Document that can be tailored to the needs of a specific mission.
9	Space Vehicle Failure Modes, Effects, and Criticality Analysis (FMECA) Guide	Aerospace Report TOR-2009 (8591)-131	Descriptive document on Failure Modes, Effects and Criticality Analysis.
10	Lessons Learned from Hosting an Infrared Payload on a Communications Satellite	J. Simonds, Space and Missile Systems Center	Interesting case study describing some Hosting challenges.
11	Guideline for Space System Late Changes Verification Management	Aerospace Report TOR-2008(8506)-8377	Includes case studies of undesired consequences from late changes that should be avoidable.
12	Test Like You Fly: Assessment and Implementation Process	Aerospace Report TOR-2010(8591)-6	Describes an assessment approach to evaluating mission related risks and potential flaws in space systems.

3. The Accommodation Process

The phases of accommodation are shown in Figure 2. Accommodation begins with identification of a hosting opportunity (Section 3.1). After a reasonable opportunity has been identified, an accommodation study can be performed to identify any requirement/capability gaps at the Payload interface (Section 3.2). Detailed design is performed to resolve gaps and mitigate risk (Section 3.3). The Payload and Host are integrated as illustrated in Figure 3, then testing verifies the interfaces and combined system (Section 3.4), allowing the project to proceed to launch and operations. Frequent interaction is required between the Host and Payload during the design and planning phases to ensure the accommodation process is successful.

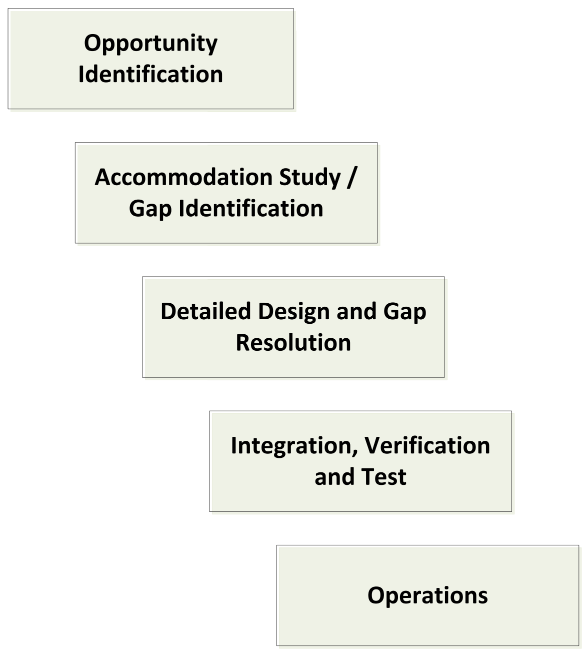

Figure 2. Phases of accommodation.

3.1 Opportunity Identification

There may be a planned or existing payload and a planned or existing host that identifies the opportunity for a business arrangement. An intermediary might also perceive and propose such an arrangement. It is expected that basic properties be matched to the first order during this opportunity phase. Basic properties to evaluate for a compatible host opportunity, sometimes referred to as size, weight, area, and power (SWAP) would include:

- Available Footprint Area
- Accommodation of Stowed and Deployed Volume
- Available Mass
- Available Power
- Temperature and Thermal Dissipation Capability
- Available Command, Telemetry and Mission Data Handling and Transport Bandwidth
- Appropriate Data Interface Capacity and Compatible Protocols

- Potential Fields of Regard (Optical and RF) plus Thermal view factors
- Frequency Compatibility
- Mission Compatible Orbits

3.2 Accommodation Study and Gap Identification

An important next step is to identify gaps between the designed and qualified capabilities of the Payload and the environments in which they will be used, so that design of any required Payload modifications or Host accommodations can begin.

Incompatibilities and gaps between requirements and capabilities of the Host and Payload require identification and resolution. A Gap Analysis is a structured method for identifying and recording these incompatibilities.

Gaps may result from:

- Untimely communication of Requirements, Interfaces or Environments
- Payload qualified environments that differ from those on the host
- Payload design capabilities that differ from those required by the host
- Late changes in requirements

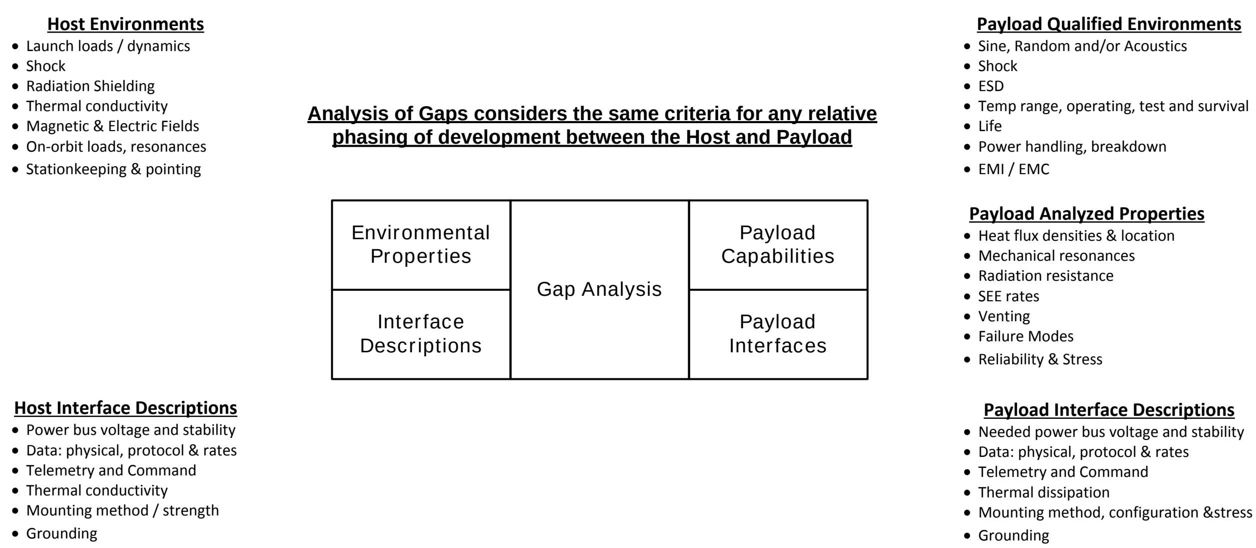

Figure 3. Identification of gaps.

Critical gaps or differences may require accommodation through design, analysis, test or operational modifications. These should be identified and tracked until resolved.

Conceptual program flow and phasing is illustrated in Figure 3. Movement of Payload development earlier or later in relation to the Host can result in disconnects or gaps in properties, handoffs, and information exchange. Disconnects can result in the need to make late modifications to one side of the interface or the other.

The graphic illustrates two of many possible approaches. The sequence in the vertical center represents flow of units to be installed, with the downward arrow going directly to the spacecraft, while the upward path represents units installed on an intermediary tower or enclosure.

When there is lack of appropriate phasing between Payload and Host development, the environmental, interface, and physical properties of the Host and Payload are unlikely to match, and accommodations will be required.

To achieve maximum risk reduction, the Payload should be available for integration with the Host prior to all relevant system level testing. To further mitigate interface risks, flight-like or high fidelity simulators should be exchanged to allow actual interface testing and verification.

Though gaps may arise due to out-of-phase development and other causes, the actual properties that must be aligned are the same for any sequence of development or for any cause.

An analysis to discover gaps should include a methodical comparison of the nominal environments that the Payload will experience to those that its components and the Payload have been designed to and qualified for. It should also include a survey of areas of potential incompatibility such as required cleanliness.

When gaps are identified, a process of resolution can be initiated. Modification of Host environments, such as temperature, dynamic stress, mechanical load or radiation can be accomplished as a means of accommodating a Payload that does not conform to baseline requirements.

Alternatively, the Payload may be found adequate by analysis or be modified by stiffening, shielding, requalification, redesign or other means.

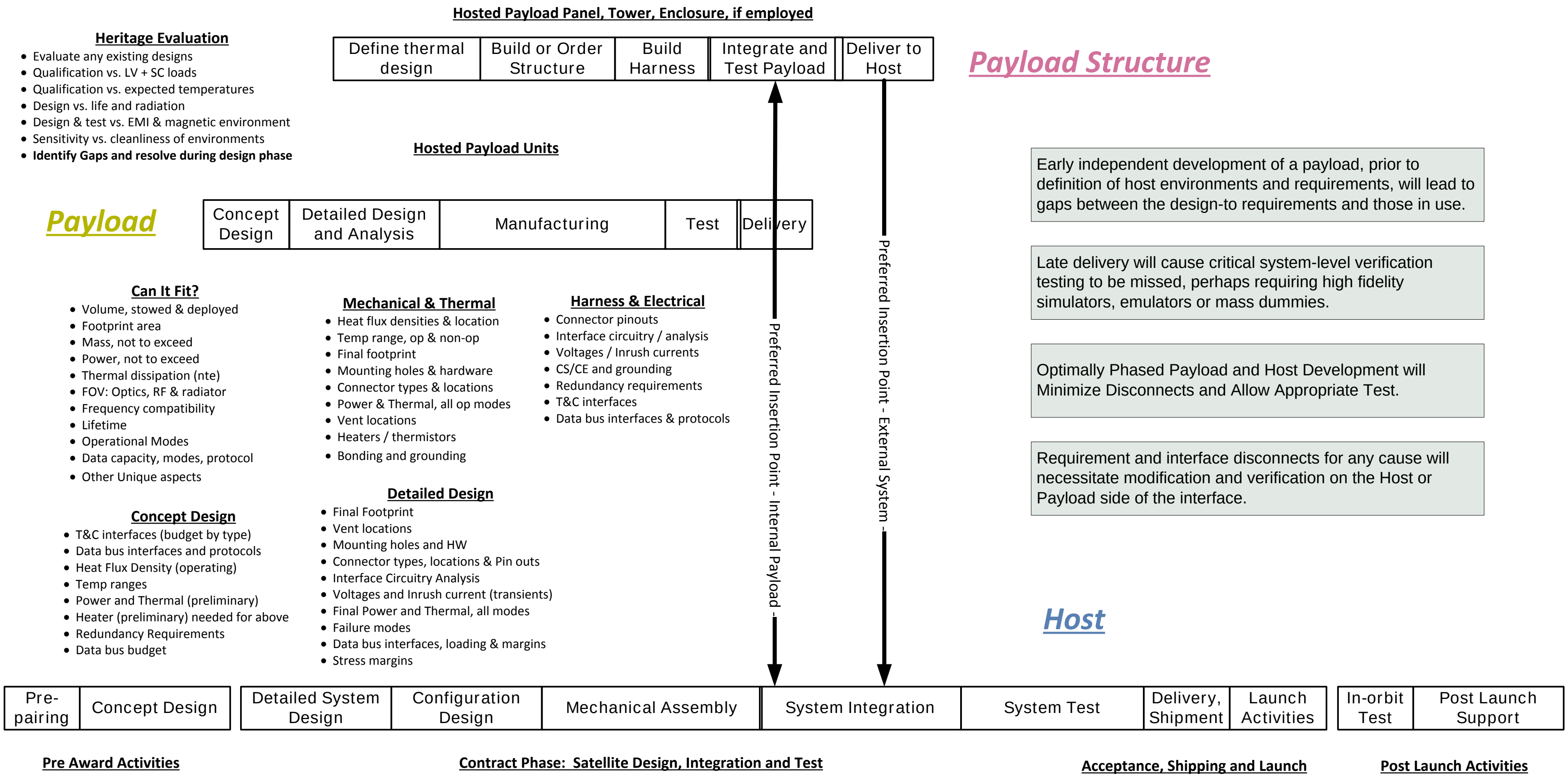

Figure 4. Optimally phased payload and host development.

If Payloads have significant thermal and structural interaction with the host, those designs will require an early start to ensure basic Host properties do not require change late in the program.

Mass, Power, Thermal and other budgets should be established early, and tracked throughout the project (Section 3.3.2).

Physical layout of equipment that might be co-located with primary mission equipment is a key consideration for accessibility, servicing and removal if necessary. Harness and electrical interface design, including routing and grounding would follow physical layout.

Ideally, interface and other analyses will be completed prior to actual manufacture and test of Payload and interfacing Host hardware and software (Section 3.3.4).

Integration and system level test (Section 3.4) should be performed according to the ideal flow shown in Figure 3 if possible. Deviations from this flow might necessitate the provision of high definition emulators or simulators.

Launch and Initial On Orbit Test (IOT) and operation on orbit come at the end of the development phase, but these and the eventual decommissioning of the Payload should be planned well in advance.

Handoffs and deliverables required to implement the program should be tracked continuously (Section 3.3.14). Key decision points will vary depending on program, but they should be established early and adhered to. Decision points as important as whether or not to include the Payload on the mission should be planned at points in the schedule where there is sufficient time to react, and alternatives such as mass simulators and closeouts should be planned, designed, or fabricated to support possible occurrences.

To achieve maximum risk reduction, the Payload should be available for integration with the Host prior to all relevant system level testing. To further mitigate interface risks, flight-like or high fidelity simulators should be exchanged to allow actual interface testing and verification.

As an added aid in gap identification and alignment of properties, checklists were developed in disciplines common across the space industry. These checklists are not meant as a substitute for the Systems Engineering Process, but as a refresher for management and systems engineering management to spark discussions in these and other areas.

Checklists for each of the areas below are provided in Appendix A.

- Attitude and Orbit Control
- Command and Data Handling
- Configuration Management
- Contamination Control
- Electrical Interface Design and Integration
- EMI/EMC
- Fault Management
- Materials and Processes
- Mechanical Layout and Integration
- Optics
- Power

- Safety, Reliability / FMECA
- Structural, Mechanical, Alignments, and Mass Properties
- Thermal

3.3 Detailed Design and Gap Resolution

When gaps are identified, a process of resolution can be initiated. Modification of Host environments, such as temperature, dynamic stress, mechanical load, or radiation can be accomplished as a means of accommodating a Payload that does not conform to baseline requirements. Alternatively, the Payload may be found adequate by analysis or be modified by stiffening, shielding, requalification, redesign or other means. The risk due to any unresolved gap is by default being assumed when it is not mitigated in some form and this must be consistent with the overall programmatic risk position.

3.3.1 Mission Operations Concepts

Early development and definition of mission operations concepts is required to ensure mission success. Interaction between ground systems of the Host and Payload, of networks and operators can be complex. Operations will vary greatly depending on each mission configuration. While design, planning, and construction of mission infrastructure is beyond the scope of this document, there are considerations that will be common across many Payload missions. Table 2 provides a starting point for mission planning from the perspective of Host and Payload interactions.

Table 2. Mission Operations Considerations

Topic	Aspect	Considerations
Mission Data	Communication of mission data from the hosted payload	Data Bus Interface (type and rate) Short term storage for mission data Use of the host data system, e.g. for low speed telemetry
	Communication with ground	Dedicated, payload provided links, e.g. for high data rate Common use of Host ground station links
Position and Orientation	Orbital Position, Orientation, Velocity and Time Information	Time stamp, clock latency and accuracy Does mission require information on board or on ground
Commanding and Telemetry	Payload commanding via the host	Payload commands and telemetry may be interleaved by the host and sent embedded to the ground with other data required by the host.
	Payload commanding via dedicated ground links	Care must be taken to ensure the correct minimum set of commands and telemetry is available as a backup via the host in order to accomplish any required contingency responses.
Mission Planning	Coordination of operations between Host and Payload control centers	Things such as simultaneous commanding from each center can be problematic. The Host, as an operational mission, will have operational priority and should define constraints on the Payload.
Fault Management and Contingency Operations		

3.3.2 Budgeted and Expendable Items

Budgeted and expendable items include mass, power, thermal dissipation and data bandwidth. Most budgeted item interface requirements are defined as “Not-To-Exceed” for the Payload and “No-Less-

Than" for the Host. For example, the Payload peak power must-not-exceed some number of watts and the Host must provide no-less-than the same number of watts. This allows both sides to perform their design and analysis activities as independently as possible. It is also incumbent on each side to manage the margin to these requirements. In the early phases of design, estimates may be rough and growth is expected as part of the detailed design.

It is important to ensure that both the Host and Payload are using the same definitions for margin in order to understand expected growth vs excess above that expectation. It is important that estimates are accurate because there is no benefit in carrying unneeded margin, and there can be harm such as inaccurate centers of mass during late stages of a program.

Many items are managed via budgets during the design of the space element. In this document, we are assuming that the host spacecraft has been designed to meet the primary mission requirements and that the link and primary mission pointing budgets are being met before hosting additional payloads.

The following budgets can be affected by the addition of a hosted payload. Most allocations should be for the Payload life, though certain aspects might be applicable for the Host mission life (e.g., propellant).

Table 3. Budgets That May Be Impacted

Item	Comment	Potential Mitigation
Mass	Need to consider the location of the center of mass.	Measurement as early as possible reduces risk. Need to consider mass simulator to protect host launch window.
Average Payload Power	Both BOL and EOL. Host must consider orbit constraints.	Hosted payload life may be significantly shorter than that of the Host. Payload power usage in all modes should be measured as part of acceptance testing.
Peak Payload Power	Both BOL and EOL. Host must consider orbit constraints. Typically driven by Payload operations but must consider all payload modes and transitions. Defines fusing design.	Hosted payload life may be significantly shorter than that of the Host. Payload power usage in all modes should be measured as part of acceptance testing.
Survival Payload Power	Power required by survival heaters and any other necessary support equipment that operates during this period.	Payload power usage in all modes should be measured as part of acceptance testing.
Power during launch and early operations	Drives maximum depth of discharge for battery.	Payload power usage in all modes should be measured as part of acceptance testing.
Pointing and Alignment	Short term (transients, jitter) and long term (diurnal, seasonal). Induced jitter, torque, and momentum exchange are factors to consider.	Short term is driven by onboard mechanisms. Use of damping or isolation can protect the other side of the interface. Long term is driven by thermal expansion mismatch. Heaters can be used to minimize the impact.
Average Conducted Thermal Dissipation	Need to define a maximum thermal transfer rate for design.	Conduction to a heat pipe panel may be considered for payloads with high dissipation.
Peak Conducted Thermal Dissipation	Needs to consider all operational modes and transitions.	Worst case conduction may bound size and materials of thermal interface.
Average Radiated Thermal Dissipation	Backload on Host or Payload can be important.	Careful review of payload radiator fields of view vs. Host configuration can reduce risk.

Item	Comment	Potential Mitigation
<u>Signals (by type)</u> Clock Analog Bi-level Pulse Relays	Quantity, format and logic convention must be addressed in ICD.	Early testing of hardware (breadboard/ brass board) can avoid late discovery of design issues. Use of simulators can help ensure incompatibilities are identified early.
<u>Telemetry (by type)</u> Data bus/Digital Analog/Thermistor Bi-level	Quantity, format and logic convention must be addressed in ICD.	Early testing of hardware (breadboard/ brass board) can avoid late discovery of design issues. Use of simulators can help ensure incompatibilities are identified early.
Command and Telemetry Data rate	Command and Telemetry bus utilization.	Separating Payload C&T bus can minimize the risk of contention between Host and Payload messages.
Mission Data Rate (Average)	Data bus and ground link utilization.	A separate payload data bus and/or downlink can reduce Host bus and link utilization.
Mission Data Rate (Peak)	Host may have capacity for much higher data rates over shorter periods.	A separate payload data bus and/or downlink can reduce Host bus and link utilization.
Processing Capability	Goal should be to minimize payload processing requirement for host.	Ground processing can reduce on-board requirements.
Memory Utilization	Goal should be to minimize memory utilization for Host spacecraft applications required to operate Payload.	Early software testing can avoid late discovery of issues.
Data Storage Capacity	When host is providing storage.	When payload provides data storage, the limit becomes data bus and ground link.
Link Utilization	Affected by orbit, pointing, C&T or, mission data rates.	Payload dedicated ground link.
Propellant	Affected by payload mass for station keeping. Affected by payload imbalance for momentum unloading.	Perform early system level analysis to optimize Payload placement and Host propulsion system flexibility.

3.3.3 Environments

Environments to which the Payload was designed, analyzed, and tested should be compared to those provided by the host. Baseline environments may be available in host environmental requirements documents. Reference 6, the NASA GEVS document, provides a good listing of environments that should be evaluated should a Host-specific document not be available.

It is recommended that Hosts publish a handbook or guide describing their environments for hosted payloads so that prospective Payloads can be designed to be compatible from the start. It should be feasible for both Payload developers and Hosts to minimize non-recurring compatibility effort by designing compatibility in from the start.

Existing payloads or their components may not be qualified to the environments of a specific host. Shock and vibration reduction techniques may be required if the units cannot be qualified to the predicted levels. Alternatively, flight units may require additional testing in order to mitigate risk.

Table 4 provides a list of key environments that should be considered. This list is not meant to be exhaustive. Other derived environmental requirements that might be relevant include magnetic fields, magnetic moments; micrometeoroid resistance; and atomic oxygen resistance for certain low earth orbits.

Table 4. Key Environments

Environment	Comment	Potential Mitigation
Shock (launch and on-orbit)	Can vary significantly by launch vehicle, placement of the Payload or missions.	• Placement in low shock areas • Use of specialized shock reduction techniques • Adding a secondary structure for the Payload can also act as a dampener if placed in the correct location
Launch Loads (sine, random and acoustic)	Will vary considerably by launch vehicle and Payload location on the Host.	• Local or spacecraft-level damping techniques can be used (CSA Soft Ride is an example) • Notching to prevent overtest
Temperatures	Host may need to support thermal control of the Payload.	• External heatpipes • Radiators • Thermal spreader plates • Thermal isolation
Depressurization rates	Depressurization rates are higher for many of the GEO launchers than for LEO launchers.	A relatively easy calculation will allow proper vent hole sizing
Partial Pressure	Partial pressure during launch and thermal vacuum pump down and repressurization can cause effects such as corona or multipaction.	Not powering the Payload during launch and pump down would be a good mitigation. Otherwise, test should be performed to ensure survival of susceptible equipment.
Vacuum	Though most space hardware is designed to operate in vacuum, many COTS products are not.	Special analysis or test might be required to ensure COTS will operate without convective cooling
Radiation	Radiation environments will vary depending on orbit, Host design and style of launch.	The radiation environment should be specified by the Host at the location of the Payload equipment. Additional shielding may be applied by the Payload to ensure equipment will operate under worst case conditions for the required duration.
Electromagnetic Interference and Compatibility	Potential interference from the Host; and stay-out frequencies required by the Host can vary from mission to mission.	Analysis and test are required to ensure there is no frequency interference between the Host and Payload. Additional filtering or shielding may be required when frequency bands or their harmonics are adjacent.
Magnetic Fields	Electromagnetic fields can interfere with instruments such as magnetometers, can affect attitude and could conceivably disturb other equipment.	Specify and respect magnetic field generation and susceptibility of both the Host and Payload.
Space Charging	High voltage potentials can build up on isolated or insufficiently grounded surfaces. Also in highly insulating materials. Either can result in damaging arcs or discharges.	Analysis and testing are required to ensure there is sufficient ESD grounding and that all signal and power returns are grounded to the appropriate ground planes.

3.3.4 Critical Analyses

Analyses required to ensure compatibility between a Payload and Host are very similar to those required to demonstrate compatibility between any other spacecraft components.

Since engineering may have been performed independently on each side of the interface, proper understanding and analysis of the interfaces is critical to the success of the project.

Structural, thermal, performance, and other analyses that are normal for spacecraft development are also required. Structural and thermal analyses are of special importance for most Payload configurations.

Table 5. Critical Analyses

Analysis	Purpose
Reliability / Redundancy (3.3.5)	Ensure that the redundancy architecture of the Host and Payload are compatible to meet the mission life and reliability requirements.
Single-Point Evaluation (3.3.6)	Ensure that potential failure modes that put the Host or Payload at risk have design fault mitigation or processes in place to reduce the likelihood of failure.
Host Failure Propagation and Fault Tolerance (3.3.7)	Ensure that propagating faults by the Host are identified to the Payload for mitigation and the identified propagating faults from the Payload are mitigated by the Host.
Payload Failure Propagation and Fault Tolerance (3.3.8)	Ensure that propagating faults by the Payload are identified to the Host for mitigation and the identified propagating faults from the Host are mitigated by the Payload.
Interface Electrical Worst Case Analysis (3.3.9)	Ensure that the interfaces will operate over all intended temperatures, radiation levels, initial tolerance and aging effects. Include derating of EEE components for reliability/design margin and successful operation during transient conditions.
Interface Timing (3.3.10)	Ensure digital signals can communicate in worst-case expected conditions.
Single Event Effect (SEE) Evaluation (3.3.11)	Ensure that semiconductor devices comply with the SEE destructive and SEU requirements in their required circuit applications.
Hazard, Failsafe and Launch Safety Evaluation (3.3.12)	Ensure that the combined design including fail-safe features, preventing premature operation, complies with the range safety features.
Mechanical and Fatigue Analysis (3.3.13)	When applicable, perform these analyses to verify that performance over mission life can be met with margin. As an example, the resulting mechanical fatigue from thermal-cycling is a factor that should be considered.
Test Like You Fly (3.4.1)	Ensures that the Payload and Host can perform as intended over all phases of the mission.

3.3.5 Reliability/Redundancy

During preliminary analyses, the interfaces should be evaluated to verify that redundancy is compatible between the Payload and Host Space Vehicle, and that any required probabilities of success are met for the combined system. Additional reliability considerations are provided in the checklists in Appendix A.

3.3.6 Single Point Failure Evaluation

Failure modes, effects and criticality analyses (FMECAs) are performed to identify and rank the severity of failures. The results of FMECAs should include identification of failure effects that are deemed unacceptable, and require design mitigation. Redundancy should be used to eliminate Single Point Failure Items when possible and practical. In cases where design redundancy is not feasible, rationale is required to justify retention of the failure mode. The most severe failure effects that are not corrected (loss or significant degradation of mission) should be documented in a Single Point Failure Item List, with this justification, for review by customers and insurance underwriters.

Failure modes can be subtle, insidious, and severe. To be effective, failure modes and failure effects should be analyzed from each side of the interface between Host and Payload, and results discussed and resolved cooperatively.

3.3.7 Host Failure Propagation and Fault Tolerance

Although failure propagation from the Payload to the Host is of primary concern, the reverse path should be addressed as well. There could be instances, such as "unintended commands" from the Host, that can affect the Payload as well as the Host.

A list of potentially propagating failures can be generated by performing an FMECA to some depth on the Host-to-Payload interfaces. That list should be provided to the Payload so it may ensure appropriate robustness against these failure modes.

An FMECA format that addresses both propagating failures from the Host and the effect of Payload failures on the host is shown in Appendix B. A propagating failure list generated from this FMECA is also included in this appendix.

Since the Host and its primary mission payloads have top priority, failure mitigation at this interface must be provided. Protection of the Host power bus from failure has the highest priority. Fusing of loads (such as the Host subsystems, and Payloads), is designed to prevent single point "mission ending failures" from failure modes, such as "shorts to ground".

Autonomous under-voltage detection and disconnect of "non-essential loads" is another "fail-safe" feature for protecting the Host power bus. Relay disconnect of smart shorts has also been included in design architectures for providing complete isolation and removing these faults that are insufficient to "clear a fuse", but continue as power consuming loads. Capacitive bypass circuits across relay contacts can provide protection from welding during "hot switching." Current-limiting designs may also be used to reduce in-rush current while charging input capacitor banks of Payloads during power-on, prior to activating a Payload DC converter.

There are no established and published ground rules for performing a fault tolerance analysis, but potential faults could be identified by performing an FMECA on the host side considering a list of propagating failure modes provided by the Payload.

3.3.8 Payload Failure Propagation and Fault Tolerance

Excerpts from a preliminary Payload FMECA and the resulting Propagating Failure Item List are also shown for a hypothetical Payload preliminary analysis in Appendix B. It is expected that most experienced space contractors will have similar formats that they can adapt for the purpose. The only thing unique about this approach is evaluation from both directions.

Though considered lower in importance than the Host and its primary mission, the Payload will typically be expensive and valuable in its own right. Fault tolerance should be evaluated in a manner similar to the Host, with the Host providing a list of potential propagating failures to the Payload.

3.3.9 Interface Worst Case and Steady State Electrical Stress Analysis

Worst Case Circuit Analyses (WCCA) ensure adequate performance margin under worst-case conditions. They consider initial temperature extremes, input voltage, part parameter variations, tolerance, and radiation degradation over the intended life. These are normally required for operational missions and payloads.

For Payload projects, analysis from the perspective of the Payload and the Host is important, since variations on one side of the interface can affect performance on the other. It is not uncommon for the Payload to have a shorter design life than the Host so, unless the Payload will be completely isolated from the Host at the end of life, interfaces would require analysis for the entire Host mission duration. However, a premature Payload failure must be considered and the required electrical isolation provided to prevent failure effects on the Host. Survival heaters by the Host should be designed to be energized as required with loss of input power from the Host to the Payload.

There are many documents describing WCCA, and many formats are used. It would probably be best if the Host took the lead in performing and documenting this analysis with the Payload provider.

The WCCA should be updated if the performance requirements of individual parts or devices do not meet their requirements or have “out of family” characteristics during subsequent lot screening tests. As an example, a Host had 1553 prime and redundant buses connected to those of the payloads with transformers. The leakage inductance of these transformers, based upon the results of a lot screening test, was “out of family”. Because of potential over-stress, identified by the updated WCCA for the input ASIC (Application Specific Integrated Circuit) in the Payload, a life test was performed on the input ASIC to verify that mission life requirements were met.

Steady-state electrical stress analysis is performed to ensure electrical components have stresses well within their capabilities over operating temperatures, so their failure rates remain low. This analysis also verifies that part manufacturer’s ratings are not exceeded even during worst-case transients. Examples might include inrush currents into tantalum capacitors.

Documented stress analysis of an operational Payload and its interfaces, correlating inputs and outputs to those of the Host, is expected.

Lower class Payloads may elect to avoid detailed stress analysis on their internal circuitry to reduce cost, or because they use existing off-the-shelf designs that will be validated by other means. Still, any interfaces that play an active role with Host electronics in a non-mitigated fashion should have the same level of scrutiny as those of the Host. Examples might include 1553 transceivers on a shared data bus, receivers of RS422 pulses from the host and survival heaters powered by the Host.

3.3.10 Interface Timing

An interface timing analysis is performed to verify that digital communications margins are met under the same conditions as the WCCA. Potential sources of “race conditions” can be identified and corrected. The analysis should be updated as needed with subsequent “out of family device performance” based upon any adverse results from lot screening.

There is no standard format for these analyses, but they are performed industry-wide. The Host should initiate timing analyses as needed. Rise and fall times and pulse polarity could fall under either timing or worst case analysis.

3.3.11 Single Event Effect Evaluation

Single event effects and potential latch-ups within the Host are analyzed by the Host to ensure appropriate availability and robustness are achieved. Those within the Payload should be analyzed for the same purpose.

It is important that no circuitry susceptible to permanent latch-up be present at the interfaces, and that the rates and effects of SEEs on interfacing circuitry be identified by the Payload and Host so that any effects that can occur on one side of the interface are either mitigated or accepted by the other.

3.3.12 Hazard, Fail-Safe and Launch Safety Evaluation

Delivery of proper documentation and analyses to the Range is the responsibility of the Host. Fail-safe features and interlocks associated with the Hosted Payload might fall fully on the Host side of the interface, but it is the Host's responsibility to ensure that it includes any necessary input from the Payload for inclusion in the Range Safety documentation (e.g., Missile System Prelaunch Safety Package (MSPSP)).

3.3.13 Mechanical and Fatigue Analysis

When relevant to the interfaces involved, additional analyses may be required. Fatigue analysis for interfaces with thermal mismatches might be one example. Each design should be evaluated to determine what additional analyses might be required.

3.3.14 Program Deliverables

Data and other analyses that might be required in addition to those analyses listed earlier in this section are provided in Table 6.

An "X" or "O" in a column indicates that the information will be delivered by the owner of that column. An "X" in a column indicates a need to share is perceived. Blank indicates no need to share is perceived. An "O" indicates it is optional, depending on the specific mission. For example, sensitive optics on a Payload necessitate assurances that the Payload will not be contaminated. Methods to accommodate a contamination sensitive payload might be shared between Host and Payload, or might be implemented primarily by one or the other as negotiated before program implementation.

Each Payload project would develop a deliverables list appropriate to the program. Also provided is the recommended phase that this information be available. It is recognized that if the Host and Payload are on different development cycles, the deliverable may not be available at the recommended time. Identifying and addressing these phase disconnects should be part of the risk management effort for the program.

Table 6. Suggested Deliverables List

Deliverable	Host	Payload	Comments	Suggested Phase/timing
Environmental requirements	X		Baseline for negotiation and subsequent design	Pre-award
Interface requirements	X		Baseline for negotiation and subsequent design	Pre-award
ICD Information		X	Phased footprint, mass, power, dissipation, finish, heat flux information, connectors and pin-outs	Start information flow at award
Command formats	X	X	For mutual evaluation	Pre PDR
Telemetry formats	X	X	For mutual evaluation	Pre PDR
Materials Lists	O	X	For contamination evaluation	Pre PDR, Updated at PDR, Final at sell-off
Parts Lists		X	For approval of any non-Space rated parts	Pre-PDR
Functional Block Diagrams	X	X	For understanding and planning	Pre PDR
Operational Description	X	X	For ConOps planning	Pre PDR
Interface schematics	X	X	For mutual evaluation	Post PDR
Industrial Health and Safety Information		X	Any integration and test hazard related information	Post PDR
Waivers, e.g. prohibited materials		X	Passed to Host operator for mission insurance documentation purposes	As encountered
Range Safety Information	O	X	Should be provided in some detail early to ensure launch base compatibility	Post PDR, Final for launch submittal
Hazard Analyses		X	For range safety	Per schedule
Orbital Debris Assessment		X	US or NASA standards	Per schedule
End Item Data Packages		X	Due diligence for insurance	As produced, e.g. at pre-ship review
Emulators and Simulators	X	X	Host and payload emulators for risk reduction test before payload delivery	Unique for each program
Electrical and Mechanical Ground Equipment	X	X	Handling, installation and offloading equipment	Unique for each program
Anomaly and non-conformance reports	X	X	For class-1 interface anomalies	As identified
Test plans and procedures	X	X	For tests to verify performance and interfaces	Prior to test

3.3.15 Aspects of On-orbit Fault Detection and Mitigation

The Host will have established fault detection, identification, and recovery practices for its bus and primary mission to respond to expected contingencies such as loss of attitude stabilization and resulting decrease in available power. To ensure there is no risk to the primary mission, a Payload will be one of the first loads shed during such a contingency. It must be able to tolerate rapid shutdown via removal of Host-supplied power with or without warning.

During significant on-orbit anomalies, Hosted and Primary Communication Payloads are expected to cease transmissions to avoid interference with and potential damage to adjacent spacecraft and on-ground

receiving facilities. If a graceful shutdown is desired, then programmed commands to cease transmissions and power down should be provided for incorporation into on-board software, scripts, or command queues. Function of these shutdown processes should be verified during system level test, before launch.

During transition of the Host to a safe mode, the optical or RF apertures, or thermal radiators, could experience direct sunlight, prolonged eclipse-like conditions, solar reflections or exposure to uplink signals. Unless the Host can, with a high level of confidence, avoid these exposures, the Payload should provide its own protection from these conditions.

These same possibilities are expected to be present during all phases of the mission including during launch, in drift orbits, during In Orbit Test (IOT) and during mode transitions. This would also be applicable to expected contingencies such as loss of lock or other detected faults.

If the Payload includes fault detection, identification, and recovery practices, these practices should be evaluated for potential risk to the Host (e.g. unexpected power draw and subsequent torque to close covers).

3.4 Verification and Test

3.4.1 System Test:

If Payload and Host schedules are compatible, and the Payload is available for installation at one of the preferred insertion points, then system level testing can proceed according to the usual spacecraft test process. Typically, this will verify mechanical, electrical, thermal, and software interface compatibility.

Manufacturers (Hosts) will differ in their approach, but a general approach is to test in the sequence in which the mission is ordered (“Test Like You Fly”). Key test phases include those listed below, though some may be considered qualification tests, and may not be repeated for heritage Host missions. The Test Like You Fly process can be implemented in a rigorous fashion by following Reference 12. Alternatively, an established Host test program might be analyzed to ensure special modes and scenarios introduced with insertion of the Payload are tested in a flight-representative manner.

- Bonding and Grounding checks
- ESD testing
- Acoustic and Sine Vibration Test
- Separation Shock Testing
- Deployment Shock Testing
- Baseline Functional Testing and/or Pre-Thermal Vacuum test
- Thermal Vacuum Test
- Antenna Test Range for Pattern and Isolation Verification
- EMI and EMC testing
- Final Functional/Post Environmental Test

Performance of these system tests verifies, with margin, the capability of the integrated Host and Payload to survive the launch environment without inducing damage to each other. It also verifies they will operate in a compatible manner, without interference.

If, for any reason, the Payload is not available for any of these verification tests then a condition of risk exists. Compatibility has not been verified. This possibility should be recognized early in the project, and appropriate mitigating actions applied. Mitigating actions might be additional analyses, or test with emulators, simulators, or engineering model structures.

Fault testing and simulation should be addressed to the greatest extent practical. Functional test of all operational and contingency modes is essential. Practicing of contingency procedures during launch/IOT rehearsals and operational training is recommended. Payload behavior should be planned for actuation of, transition to, and survival in all Host safe modes.

3.4.2 Verification

Verification is the process for ensuring that the final design meets its requirements. In this case, we are concerned about whether the Host and Payload designs meet the requirements for their shared interface. The set of critical requirements for a hosted payload will be developed and negotiated between the Host and Payload and should be documented in an Interface Control Document, a Requirements Document, or a similar set of documents. Not all requirements for a Payload are needed in such a document, but those related to interfaces and properties that are necessary for Host compatibility, including its launch and operation, are considered necessary. Many of those considerations are addressed elsewhere in this TOR.

Requirements should be developed as verifiable statements. Vague or non-specific requirements leave too much open to interpretation. Verification requirements should also be specified in the requirements document. At a minimum, verification requirements should include the required assembly level and method for verifying each technical requirement. Industry practice is to verify requirements by Analysis, Test, Inspection, or Demonstration.

Verification planning and definition of methods should be established early in the program to ensure there are no unverified requirements at the end. A typical approach to verification planning starts with creating a requirements verification matrix that defines the verification approach and pass/fail criteria.

The space industry has developed standards by which all contractors follow consistent practices for verifying and testing space products. These standards are explained in detail in references such as TOR-2006(8506)-4732 Space System Verification Program and Management Process, MIL-STD-1540 Test Requirements for Launch, Upper-stage, and Space Vehicles, and TOR-2004(8583), Test Requirements for Space Vehicles. A delta-qualification review may be necessary to ensure that the Hosted Payload is qualified to operate in the mission environment of the Host.

As programs mature, verification details should be updated and reviewed at key milestones. As each verification event is completed the verification matrix is updated to show the results and compliance. For parametric properties the matrix should incorporate predicted values, then values verified by test. Any differences between the requirements and actual properties that are uncovered during the program should be addressed using Waiver, Deviation, or Nonconformance processes to determine their acceptability.

3.4.3 Risk Reduction/Payload Acceptance Test:

System test effectively validates the intended mission performance. Lower level interface testing is performed to reduce the risk of discovering incompatibilities and failures at the system level.

Testing with the actual Host interfaces is ideal. Testing of engineering model or brassboard Payload equipment on a Host test bed, if possible, is a good method of risk reduction. The possibility that mockup circuits, or Host engineering, or qualification models might be made available for this testing should be explored.

Acceptance testing of Payloads and their equipment should be performed to industry norms to ensure no design deficiency or random defect will jeopardize the mission of either the Host or Payload.

The order of tests can vary, but will generally include the following.

- Baseline Electrical
- Non-operational Thermal Cycling
- Shock (typically only for qualification test)
- Sine Vibration
- Random or Acoustic Vibration
- Thermal Vacuum Test, with measurements at nominal and extreme temperatures
- ESD testing (typically only for qualification test)
- EMI/EMC testing
- Final Functional Test

Additional testing specific to the system under consideration may be useful to further reduce system test risk.

3.4.4 Verification of Mixed Class Missions

Hosted payloads may be of lower quality than the operational missions that host them. Government programs, for example, are classified by level, with Class A being an operational mission with all assurance practices applied. Lower classes may be pathfinders, experiments, or concept verification projects. Operational commercial spacecraft use high quality components with thorough analysis and test. They are analogous to government Class A missions, though they typically use only high Technology Readiness Level equipment to reduce technical and schedule risk.

Lower classes, such as Class D, may use COTS units made using lower quality parts and without the control over materials and processes expected of operational flight products. This could be considered a gap in requirement levels. Test rather than analysis may be the only way to ensure compatibility in certain respects.

It is important to note that regardless of the class designation of the Payload, the class of the Host will drive the relative class of the Payload to Host interfaces. Thus, in the case of the typical GEO commercial communications spacecraft, which is insured for a 15+ year primary mission, the Host is considered Class A and demands Class A Payload interfaces and verification.

Risk reduction evaluation tests to verify the capability of units proposed for use on an operational mission should be performed early in the Payload design phase. An example test would be for condensable volatiles if COTS components are included in the payload design. Lower class verification methodologies will need to be accepted by the Host and Operator as part of the Mission Assurance and Systems Engineering processes.

Higher class operational Hosted Payloads that incorporate internal redundancy may expect robust and redundant interfacing support equipment from the Host. Lower class missions might require less support in accordance with their lower cost approaches. As an example, a single-thread (no redundancy) Class D mission might not require redundant command or power from the Host, while an operational Class A payload would.

4. Summary, Findings, Conclusions, and Recommendations

During the development of this document, team members shared their personal and company experiences, conducted interviews, and researched publications on hosted payload projects. The compiled information seemed to reveal patterns worth emphasizing.

Common themes increasing risk included insufficient information sharing between Host and Payload; lack of knowledge of Host requirements, configuration, con-ops and environments during Payload development; and lack of direct involvement between Host and Payload during technical planning.

Key recommendations and thoughts from the team include:

- Host and Payload providers should define their roles and responsibilities as early as possible.
- Payload equipment providers and the Host should interact directly and frequently.
- A system-level gap analysis should be performed by the Host and Payload teams at program inception to identify disconnects and plan accommodation.
- Open communication channels should be established between Host and Payload specialists, so that models and interfaces designs can be exchanged and negotiated.
- Standards and definitions should be agreed upon at program inception.
- Simulators and emulators should be used prior to payload integration to reduce interface risk.
- Payload providers should support system-level test planning and testing at the Host facility.
- Payloads should be tested realistically with the Host after systems integration.

The authors and reviewers of this document strongly recommend that potential Hosts publish and distribute environmental and interface requirements and that potential Payloads review and consider these at the earliest practical phase of development

Table 7 lists some of the difficulties that were experienced, with likely root causes and steps that might have resulted in avoidance of the problem.

Table 7. Experiences on Hosted Payload Projects

Phenomenon	Likely cause	Mitigation
Gain ripple in a hosted payload signal due to interference between the hosted payload and its back lobes reflecting from primary payload structure.	Hosted payload not tested with an assembled spacecraft in the system level antenna test.	Test like you fly whenever possible. If this cannot be done, the off-nominal test sequence should be elevated and tracked as part of the risk management process.
Instrument baffle had to be trimmed due to physical interference with deployed appendage.	Inadequate exchange of configuration information.	Early exchange of physical model (e.g., Pro-E) data.
Hosted payload tested in excess of its thermal capabilities after installation onto the host.	Host personnel unaware of Payload limitations.	Participation of Payload personnel in test design and system test with host.
Outgassing of chamber damaged Payload optics.	Lack of communication and verification between host and payload.	Participation of Payload personnel in test design and system test with host.
Payload survival heaters were not powered during T/V testing.	Lack of communication and verification between host and payload.	Participation of Payload personnel in test design and system test with host.
Lack of clear requirements and baseline caused numerous design iterations and “scope” claims.	Insufficient definition of requirements.	Clear standard requirements up front.
Power on transients were encountered when mating up a payload with the host.	Transients were not specified by host, and current limit style was not communicated.	Design details should be shared early and interfaces tested early.
A significant redesign was needed because of clearance and routing interferences.	Volume envelope did not account for variability and intrusions.	Work together to fully understand volume limitations including screw heads, wiring and cabling, gaskets, dynamic displacement, multi-layer insulation, and tolerance stack-up.
Host venting paths distributed contamination into Payload optical cavity.	Insufficient cooperative design of contamination prevention program.	A careful contamination control program should be developed whenever there are contamination sensitive components on the Host or Payload.
Payload units qualified to dynamic load levels per existing noncommercial (NASA GEVS) standards, insufficient to meet commercial geosynchronous load levels.	Lack of awareness of commercial requirements differing from NASA, due to use of a wider range of Launch Vehicles, for example.	Detailed dynamic load “gaps” comparison performed as early as possible to ensure compatibility. Loads analysis performed and risk mitigation plan put in place if Host and Payload requirements contain “gaps.”

Appendix A. Checklists

The checklists provided here are intended to help spur the thought process throughout a payload project. They are based on the experiences of individuals in our group and of their companies. They do not provide a cookbook for hosting payloads, nor should they be considered a replacement for the Systems Engineering process that is required to appropriately host a payload. In the initial phase of Payload accommodation the Host and the Payload Provider need to apportion responsibilities for these checklist items.

Line items are numbered sequentially in each discipline, with leading abbreviations as shown in Table 12.

Table 8. Key to Areas of Expertise

AC	Attitude and Orbit Control
CD	Command and Data Handling
CM	Configuration Management
CC	Contamination Control
EI	Electrical Interface Design and Integration
EM	EMI/EMC
FM	Fault Management
MP	Materials and Processes
MI	Mechanical Layout and Integration
OP	Optics
PW	Power
SR	Safety, Reliability/FMECA
SM	Structural, Mechanical, Alignments and Mass Properties
TH	Thermal

Table 9. Additional Reference Documents for Appendix A

	Title	Document	Function
A1	Electromagnetic Compatibility Requirements for Space Systems	MIL-STD-1541	Establishes EMC requirements for space systems.
A2	Space Power Standard	SAE AS5698	This standard defines the requirements and characteristics of electrical power for spacecraft. It also defines analysis, verification, and testing methodologies.
A3	Technical Requirements for Electronic Parts, Materials, and Processes Used in Space Vehicles	Aerospace Report TOR-2006 (8583)-5236	Establishes the minimum technical requirements for electronic parts, materials, and processes.
A4	Instructions for EEE Parts Selection, Screening, Qualification, and Derating	NASA/TP-2003-212242; EEE-INST-002	Establishes baseline criteria for selection, screening, qualification, and derating of EEE parts on space flight projects.

Attitude Control

Attitude Control, pointing, and orbit determination are related topics from a Payload point of view. Payload designs that require pointing control will depend at least in part on the Host for assistance on meeting pointing performance. Note that any change to the normal Host ConOps to accommodate the Payload may influence both the Host design and the Owner/Operator's mission operations resources. Additionally, incorporation of the Payload should not degrade the Host's pointing and attitude control performance such that primary mission objectives are not met. The following items should be considered when evaluating the feasibility of the Payload accommodation.

Table 10. Attitude Control Checklist

Item	Topic	Consideration	Comments
AC1	Pointing	Pointing requirements.	The pointing requirements will be driven by the payload with the tightest requirements (Primary or secondary).
AC2	Disturbance/Jitter	Disturbances generated by the host at the payload interface (rotational and translational amplitude and frequency content).	Structural dynamics are a significant factor in the pointing budget.
AC3	Disturbance/Jitter	Disturbances generated by the payload at the payload interface (uncompensated momentum, torque and jitter amplitude and frequency content).	Payload should compensate for, or be able to tolerate, any moving masses required during operation.
AC4	Knowledge Requirements	Host ephemeris and attitude knowledge (position and rate; accuracy; update rate and latency) should be defined in ICD.	Is this data required for payload ConOps? Is this data required for on-board or for ground processing?
AC5	Host Maneuvers	Spacecraft Maneuvers (Delta V, Momentum dumps).	ConOps must consider if payload can meet its mission during maneuvers. If it cannot, does host need to provide schedule to payload or create special ConOps?
AC6	ConOps	The host Owner Operator should coordinate spacecraft maneuvers with the Payload.	The degree of coordination would normally be contractually agreed prior to starting the project.
AC7	Payload Field of Regard	Payload field of regard must consider Host spacecraft Agility.	Is payload Field-of Regard and control system adequate for expected host attitude changes?
AC8	Mass Properties	Payload must provide mass, center of gravity, and inertia during all mission phases for attitude control use. Does payload deploy?	If payload is late, will a mass simulator be required?

Item	Topic	Consideration	Comments
AC9	Orbits	Payload orbital drag, Center of Pressure during all mission phases.	Does host need to provide compensation to reduce propellant usage?
AC10	Failure Modes	Can Host perform mission with failed Payload deployment (at any point in deployment)?	Will the failure impact primary mission? Will payload meet frequency requirements with failed latch-up?
AC11	Stability Related	Payload Thermal stability.	Any thermally driven disturbances.
AC12	Structure	Payload Structural frequency.	Is payload frequency low enough to require coupled analysis?
AC13	Dynamic Models	Stiffness.	Will a dynamic model be needed for coupled analysis?
AC14	Nonlinear Dynamics	Payload dynamics nonlinearities.	Payload should provide nonlinear dynamics behavior to Host for design of the control system.
AC15	Coordinate Reference Frames	The SC contractor and Payload Contractor(s) shall jointly agree on a method to define the transformations between the SC Attitude Reference Frame and the Payload Reference Frame.	Pointing, knowledge, and mass properties all depend on axis definition.
AC16	Glint	Is payload visible to any ACS sensors? What is the surface material? Is Host visible in payload Field of Regard?	Stay-out zones for payload radiators, glint-free zones, and other restrictions, shall also be specified in the ICD.
AC17	Payload Safing	Payload Field of view constraints (Payload safety).	Must payload be protected from sun or earth view during nominal operations or safe mode transitions?
AC18	Orbit Limitations	Payload may only be able to meet Payload mission requirements in certain orbits or orbital arcs/longitudes due to RF coverage, signal strength, line of sight, power or thermal.	Are the potential Host orbits and tolerances compatible with Payload orbit constraints?
AC19	Payload Safing	Does Host need to provide a safing command to payload before orbital maneuvers?	

Command and Data Handling

Command and Data Handling includes command through the Host to the Payload, and return telemetry that might be routed through the Host C&DH subsystem. Telemetry and information might also be delivered directly to the ground by a hosted payload if Host on-board processing does not have sufficient bandwidth for the task.

Table 11. Command and Data Handling Checklist

Item	Topic	Consideration	Comments
CD1	Links	Does payload have its own ground links?	
CD2	Margin	In budgeted items, is there enough contingency/margin for growth based on design phase?	Do host and payload use the same definition of “Contingency” and “Margin”?
CD3	Data Storage	Is storage onboard the Host required? Is it partitioned or shared?	Shared memory requires higher levels of testing to assure no impact.
CD4	Data Storage	Is storage margin enough to upload payload SW updates?	Future SW updates can be overlooked.
CD5	Data Bus	Is encryption of payload data, telemetry and/or commands required?	Who is responsible for encryption? What encryption protocols? How does this influence the ground system?
CD6	Telemetry Dictionary	Payload Telemetry dictionary should include: data type, format, protocol definition, units, expected frequency.	If multiplexed, payload must describe method for data extraction.
CD7	Command Dictionary	Payload Command Dictionary should include: purpose, preconditions, restrictions on use, format, protocol definition, command arguments and data types (including units).	Must include nominal and off nominal cases.
CD8	Error Checking	Does payload perform any error checking on commands?	If error checking is not performed, procedural methods should be employed to protect payload.
CD9	Data Format	Payload data formatting must be compatible with Host data bus.	Host must provide formatting requirements.
CD10	SOH Telemetry	Payload should provide unencrypted State of Health telemetry.	Prefer at all time, at minimum during anomaly.
CD11	Isolation	Payload telemetry signals must have failure isolation.	Consider temperature sensors and housekeeping data.
CD12	Processing	Processing margins need to consider all modes for both primary and secondary payloads.	
CD13	Timing	Accuracy, stability of timing signal.	Can be an issue if payload has tighter requirements than host. Payload may need to provide own timing.
CD14	Timing	Do payload and host have compatible major/minor cycles?	
CD15	Fault Detection	Does payload perform any fault detection?	Consideration for fault management design.

Item	Topic	Consideration	Comments
CD16	Fault Reporting	Does payload perform any fault reporting?	Consideration for fault management design.
CD17	Lock Out Preclusion	Payload must be precluded from locking out commanding.	Host may need to reset payload in fault situation.
CD18	Remote Terminals	Payload remote terminal must be protected so that it cannot become the data bus controller.	
CD19	Remote Terminal	In fault scenarios, payload RT cannot write to both primary and redundant data bus.	
CD20	Remote Terminal	Is Remote Terminal Addressing fixed or reconfigurable?	Failure mode.
CD21	Contingency Operations	Payload must have the ability to inhibit automatic redundancy switching (if applicable).	Automatic switching can keep commands from getting to payload.
CD22	Modes	Payload should provide four modes: Operation, Safe, Initialize/Standby, Survival.	Payload may have several sub-modes within these modes.
CD23	Contingency modes	In all modes except Operation, payload should limit data to that required for payload health and status.	
CD24	Safe Mode	Payload should not inhibit any safe mode transition whether via command from Host or Ground or detection of internal anomalies.	Host needs ability to override payload for anomaly response.
CD25	Operation mode	Payload should only enter operation mode upon receipt of a valid command from Host or Ground.	
CD26	Fault Protection	Apply independent fault protection, such as hardware watchdogs, to mitigate risk in real-time systems.	Errors can be so deeply buried as to be practically undetectable.
CD27	End of Life Plan	Payload should place itself into a “safe” configuration upon reaching its end of life to prevent damage to the Host Spacecraft or any other payloads. Payloads often have shorter missions than their Hosts.	The payload may have potential energy remaining in components such as pressure vessels, mechanisms, batteries, and capacitors, from which a post-retirement failure might cause damage to the Spacecraft Host or its payloads. Safe conditions at EOL should consider thermal and radiation environments.
CD28	Firing and Motor Circuits	Protect firing circuits against sneak currents and line-to-ground shorts.	Components such as step motors and pyro circuits that experience sudden current changes should be isolated from all other current-carrying circuits including power, control, RF transmission lines, and monitoring circuitry.
CD29	Testing	Host and Payload Test Ports should be separated and Isolated.	Allows easier troubleshooting during integration.
CD30	Interface Compatibility Testing	Hardware and software compatibility from different vendors should be verified during design.	COTS data sheets do not cover all interface parameters.

Configuration Management

A cohesive process for configuration management must be defined so that both the Host and Payload are kept current with critical program information affecting both parties. Configuration data should be adequately documented and archived for ease of reference and retrieval. Information that needs to be exchanged and placed under the common configuration management process should be defined in the contract or statement of work.

Configuration management is critical for capturing changes as they occur, can prevent surprises, and optimize performance if mutually beneficial actions are implemented. The definition of a mutually beneficial action is one that resolves an issue for one or both missions with minimal cost and schedule impact to either. It is critical that impacts to both missions are identified and understood prior to the decision to implement a change. Otherwise, the resolution of one issue may result in an even greater problem. Sometimes, a mutually beneficial decision is not possible, in which case a compromise decision may be in order. The worst decision would be one that resolves one issue without any regard to impact on the other mission.

The Payload should be included in change control activities for modifications that have potential to affect their mission.

Table 12. Configuration Management Checklist

Item	Topic	Consideration	Comments
CM1	Technical requirements	Configuration management requirements must be defined and communicate changes as they occur in the technical and programmatic requirements on either the host or payload if they impact the other. A change control process needs to be in place.	Included are documentation of agreements and revisions to environmental, operational electrical, mechanical, software, and algorithms that impact host/payload relationship. This shall include design phase as well as post payload to host delivery.
CM2	Unresolved issues	Tracking and resolve design issues (TBDs).	Resolving issues such as what the outer material on layers of multi-layer insulation should be completed early enough to permit incorporation of that change into the design of the host or payload.
CM3	Test plans and results	Documentation, planning, and the results from mechanical, electrical, and RF pathfinders and from tests that impact host/payload relationships must be distributed and controlled.	Control needed to eliminate surprises and demonstrate performance.
CM4	Interface	Interface documentation of mechanical, electrical, software, firmware, and communications commonalities must be controlled.	It is important to keep track of host/payload changes that would impact the other. Post payload delivery decisions that impact interfaces should include payload representative for approval.

Item	Topic	Consideration	Comments
CM5	Thermal	Modifications to the thermal design requirements and test results of either the host or payload must be documented in a controlled manner.	Thermal design of either the host or payload may require (or benefit from) modifications of either the host or payload depending on the selection of materials and usage. Thermal design includes interface power, thermal control services, and common nodes as well as spacecraft orientation, ConOps, and understanding the effect of external structures such as antennas, thermal blankets, and solar arrays.
CM6	Mechanical and Structural	Mechanical and structural documentation, planning, and test results that impact host/payload relationships must be distributed and controlled. Representative mass mock-up of the payload should be provided for host testing of mass properties, vibration, and shock.	A physical confirmation well in advance of the installation of the payload should take place to confirm the interface. If the payload is not available, a mass mock-up that represents the weight and cg of the payload should be provided for testing, or to replace the Payload if it is late.
CM7	Mechanical and Electrical Design Documentation	Allow host and payload viewing of design of components identified in the interface control documentation payload design. A change control process needs to be in place.	Ensure design software used is compatible. Viewer programs exist for nearly all design applications.
CM8	ConOps	Definition of the Concept of Operations that impact host/payload relationships must be distributed and controlled.	The impact on a payload, for example, if it is required to operate in full sunlight could be very important if it were designed to operate only in the shadow.
CM9	Control of Design	Involve the Host and the Payload in "use-as-is," "rework to specifications," decisions that impact the other or the interfaces.	Avoid potential failures due to lack of understanding of impact on the Payload.
CM10	Prohibited Materials	A prohibited materials list must be maintained.	This would provide a clear impact of materials utilized to the other party.
CM11	Control of Support Materials	An approved support materials list should be maintained.	This would provide a checklist of materials that can be used in vacuum with flight equipment.
CM12	Test Results	Capture, explain, and document testing on the unit under test that impact host/payload relationships must be distributed and controlled.	Sets expectation for integration testing.
CM13	Test Procedures	Provide intended test procedures and conditions that impact host/payload relationships must be distributed and controlled.	This includes such aspects as ramp rates, temperature cycles, power levels, data acquisition rate to ensure that conditions planned by the host will be acceptable to the payload design.
CM14	Assembly	The host shall coordinate the control of mating procedures and cable routing.	Ensure alignment of needs.

Item	Topic	Consideration	Comments
CM15	Control of Analysis Tools	Input parameters, assumptions, starting/boundary conditions must be consistent between Host and Payload if analysis roles are shared (thermal, structural, RF, etc).	Reduces chance of misleading results or incorrect conclusion that a "gap" may exist or not.
CM16	Access to Information	The Payload provider should ensure Contractor access to interfacial design information in a timely manner.	The Payload provider may obtain parts, units, or processes from outside vendors or US government sources. This may inhibit the Payload provider from sharing key interface information with the Host/Contractor in a timely manner, hindering the design process.
CM17	Parts and Materials Lists	Parts and Materials lists are standard for the Host. Similar lists should be provided by the Payload for host review.	Part requirements for the Payload may be different from the Host, but all should be robust against the space environment.

Contamination

When either a Host or Payload has contamination sensitive equipment such as optics; detectors; highly sensitive thermal surfaces; or equipment that is to be operated at significantly colder temperatures than adjacent areas and equipment, contamination requirements should be defined. Because of differing requirements and manufacturing flows, it's necessary for the payload and host to jointly negotiate a detailed contamination control plan that ensures sufficient cleanliness during manufacturing, test, shipment, and launch, as well as on orbit.

On-orbit contamination measures such as foreign object debris (FOD) restrictions or venting pathway design may also be required. It is anticipated that both the host and the hosted payload will incorporate some measure of protection from contamination, particularly if there is a sensitive payload involved.

A particular area of concern is the use of commercial-off-the-shelf (COTS) equipment. Since COTS equipment manufacturers do not normally consider space environments in the design of their equipment, verification of compatibility by test and/or preventive measures are required. Monitored bakeout is an example of test and preventive measures.

Table 13. Contamination Checklist

Item	Topic	Consideration	Comments
CC1	Purge Requirements	Purge requirements must be defined early to design gas transmission for shipment, integration, dynamics, T/V, EMI, and at launch base.	Purge requirements should be avoided if they are not critical for performance of the Host or Payload.
CC2	Purge Rates	Purge rates should be compared to available gas supply for shipments to ensure sufficient supply for contingencies.	

Item	Topic	Consideration	Comments
CC3	Purge Gas Safety	Purge gasses are likely not gasses that support life. Areas where purge is to take place should be surveyed to ensure no gas buildup is possible.	
CC4	Bagging	Bagging is likely needed to protect sensitive surfaces in a normal high-bay environment.	Bagging, also, should be avoided unless necessary for thermal or optical performance.
CC5	Bagging and Dynamics Testing	Bagging should be designed to not interfere with any acoustic or vibration testing.	
CC6	Bagging and EMI and RF Testing.	It might be advisable to use RF transparent bagging so that sensitive surfaces need not be exposed during EMC and other RF testing.	
CC7	Cryogenic Temperatures	Ground operations that are required at cryogenic temperatures should be planned in advance to ensure appropriate environments.	
CC8	Thermal Vacuum Testing	It is unlikely that bagging will be effective during pump down. Purging during pump down is also difficult.	Special planning may be required to maintain cleanliness during T/V testing.
CC9	Thermal Vacuum Testing	Sensitive surfaces should be kept warmer than the surroundings during repressurization if possible to avoid condensation of plasticizers and other contamination.	
CC10	Launch Base	Launch base cleanliness varies from site to site. Geosynchronous launch facilities may be class 100,000 as may fairings.	Plans to maintain cleanliness at launch base should be made well in advance. Purge carts and filters must be manifested months in advance of launch.
CC11	Launch	Sensitive surfaces should be maintained warmer than their surroundings, or should be covered with deployable covers, during ascent to avoid condensation of contaminants.	
CC12	Post-launch	Cryogenic surfaces can condense materials even in the near-vacuum of space. Consideration should be given to allowing time for the host or payload to outgas before going cryo or opening deployable covers for optics or radiators.	Primary payload could be tested in orbit while spacecraft and payload outgas and dry.
CC13	Bakeout	Consideration should be given to baking out surfaces (e.g., blankets) near a sensitive payload.	
CC14	Thruster Plumes	Plumes for liquid propellant thrusters should be modeled to ensure their impingement and collection rates on sensitive surfaces are acceptable.	

Item	Topic	Consideration	Comments
CC15	Sputtering Products	Sputtering products resulting from electric propulsion use should be modeled to ensure their impingement and collection rates on sensitive surfaces are acceptable.	
CC16	COTS	COTS products are not designed for low outgassing rates and should be thoroughly investigated and tested to ensure they will not affect sensitive surfaces.	
CC17	Vacuum Compatibility	Needless to say, all materials used within a vacuum chamber with a sensitive payload should be controlled and vacuum compatible.	Zinc, Cadmium, Mercury and other metals can sublime in vacuum and redeposit on cold surfaces. Many organics can also contaminate.
CC18	Cleaning	Cleaning procedures after delivery should be specified, as should any support equipment and environmental requirements.	
CC19	Cleanliness Requirements	Cleanliness requirements can influence effort. For the most economical mission, expensive operations such as purge in the fairing should be avoided.	
CC20	Venting Analysis	A venting analysis should be performed to determine the flow path and flow rates that will occur during decompression to a vacuum. These vent paths need to be steered away from sensitive surfaces.	
CC21	Venting Paths	Venting paths should be checked to ensure they do not vent into contamination sensitive areas.	
CC22	Thruster Locations	Thruster locations should be checked to ensure their plumes will not affect contamination sensitive areas.	
CC23	FOD	Ensure apertures and openings are protected to the extent possible. Implement FOD control procedures.	

Electrical Interface Design and Integration

The proper operation of electrical interfaces between the Host and the Payload is fundamental to the success of the combined missions. Electrical interfaces are susceptible to subtle effects that are sometimes difficult to analyze. Additionally, integration of the Payload with the Host may occur late in the Host's integration flow. This potential for late discovery of electrical interface design issues represents a significant risk to the Host.

This risk can be mitigated by implementing a sound electrical interface design and validation approach. Robust and comprehensive interface requirement definitions that incorporate appropriate performance margins can significantly reduce the risk of non-functioning interfaces. Further risk mitigation is encouraged thru the execution of interface validation testing not only as part of unit acceptance test but also with early end-to-end demonstrations using engineering models and flight like harness assemblies. Lastly, forethought is required to ensure that damage is avoided during Host-Payload integration by implementing appropriate connector inspection and mating criteria.

Table 14. Electrical Interface Design and Integration Checklist

Item	Topic	Consideration	Comments
EI1	Configuration Management	Documentation defining the electrical interfaces must be controlled and/or approved by the Host. Typically, documentation of interfaces is captured in an Interface Requirements Document (IRD), Interface Control Document (or Drawing) (ICD), and in Schematics.	The Host is ultimately responsible for ensuring that the electrical interfaces will not induce harm to the primary mission. Uncoordinated interface design changes by the Payload must be prevented. Similarly, arbitrary changes by the Host could degrade the Payload's performance.
EI2	Requirements	Develop comprehensive requirements for each interface type needed to support the payload (power, digital data, RF modulated data, command and telemetry signals, pin programming, etc.).	Definition of voltage levels, timing characteristics, and modulation methods are key items. Additionally, definition of data and message protocols should be included to ensure compatibility.
EI3	Requirements	Signal characteristics should be defined at the connector interface between the host and the payload.	This will prevent potential gaps in interface analyses in cases where the Payload provides a portion of the interfacing harnesses.
EI4	Analysis	Perform Worst Case Circuit Analyses on the electrical interfaces to ensure that all interface types will remain within specification throughout mission life.	Refer to section 4.4.5 and 4.4.6 for a detailed description of Interface Worst Case and Timing analyses.
EI5	Analysis	Harness voltage drop and signal attenuation effects must be considered to ensure proper operation of the Payload.	This is necessary to ensure that an adequate DC voltage level is provided to the Payload units and that the telemetry and command signal work properly.

Item	Topic	Consideration	Comments
EI6	Analysis	Perform reliability and failure mode analyses to ensure that the failure modes of the interface and their probability are well understood. This must include evaluation of potential single point failures and propagating failures. Permanent effects from Single Event Effects (SEE) analysis such as Latchup should also be included in the failure mode analysis.	This analysis provides important data for development of Fault Protection features in the Host and the Payload. See the Safety and Reliability Checklist for more details.
EI7	Harness/Cable Lengths	Care must be taken when determining the cable lengths between Host and Payload. Long, circuitous routes may be needed to host a payload.	Detrimental effects such as voltage drop, signal attenuation and cross-talk all vary with cable length.
EI8	Return Paths	Signal and Power return paths should be matched between the Host and the Payload.	See the Power Checklist for additional considerations for power and ground interface considerations.
EI9	Mis-mates	Prevent mating the wrong connectors together by utilizing variations in connector type, keying features, and color coding. Use unique connector ID markings as much as possible on the units and harnesses.	Units made up of multiple identical slices are the most likely to experience mis-mates.
EI10	Shielding	Determine whether interfaces are susceptible to cross-talk interference from other lines in the harness bundle and define appropriate wire type, shielding or separation requirements.	
EI11	External Harnesses	Harness bundles that are external to the Host vehicle's Faraday cage will need additional shielding to mitigate ESD susceptibility, radiation damage, and micrometeoroid damage.	
EI12	Validation and Test	Interface risk can be reduced with early validation of interfaces using engineering models or interface simulators to perform compatibility tests. Duplicate flight harness types and lengths to ensure representative results.	Early demonstration of interface compatibility should be performed whenever possible to reduce risk of integration delays late in the program.
EI13	Inspection	Introduction of new connector types may require updates to the Host's existing generic inspection criteria for connector mates and demates.	
EI14	Assembly Planning	Introduction of new connector types may require special planning instructions for proper execution of connector mates and demates.	Special tooling, torque requirements and fastener definitions for new connector types must clearly defined for the integration technicians.

EMI/EMC

The performance of the Payload and of the Host can potentially be degraded by either radiated electromagnetic interference (RF) or conducted electromagnetic interference (line noise, ripple, etc.) between the two entities. It is critical that detailed requirements be established between the two entities to ensure that electromagnetic compatibility is achieved. Specifically, that both the Host and the Payload will be safe and will operate properly for all operating modes and mission phases.

Table 15. EMI/EMC Checklist

Item	Topic	Consideration	Comments
EM1	Radiated Emissions	Establish interface requirements for the minimum allowable radiated electromagnetic emissions safety margins between the Host, the Payload and the launch vehicle.	Note that the margin required may vary between these three entities.
EM2	Radiated Emissions	Define the radiated emissions environment generated by the Host.	
EM3	Radiated Emissions	Define the radiated emissions environment generated by the Payload.	
EM4	Radiated Emissions	Define the radiated emissions environment generated by the launch vehicle and by other systems at the launch site.	
EM5	Radiated Susceptibility	Define the radiated emissions limits that are imposed by the Host.	
EM6	Radiated Susceptibility	Define the radiated emissions limits that are imposed by Payload.	
EM7	Radiated Susceptibility	Define the radiated emissions limits that are imposed by the launch vehicle and its systems.	
EM8	Radiated Susceptibility	Identify all frequency ranges for which the minimum radiated emission safety margin is not satisfied for the Host, the Payload and for the launch vehicle. Examine potential design changes and/or more extensive EMI/EMC testing that will improve and demonstrate safety margins and compatibility for these frequency ranges.	
EM9	Conducted Emissions	Establish interface requirements for the minimum allowable conducted electromagnetic emissions safety margins between the Host, the Payload and the launch vehicle.	Note that the margin required may vary between these three entities. Conducted emissions are transmitted through the direct electrical interfaces between entities.
EM10	Conducted Emissions	Define the conducted emissions environment generated by the Host.	
EM11	Conducted Emissions	Define the conducted emissions environment generated by the Payload.	

Item	Topic	Consideration	Comments
EM12	Conducted Emissions	Define the conducted emissions environment generated by the launch vehicle.	
EM13	Conducted Susceptibility	Define the conducted emissions limits that are imposed by the Host.	
EM14	Conducted Susceptibility	Define the conducted emissions limits that are imposed by Payload.	
EM15	Conducted Susceptibility	Define the conducted emissions limits that are imposed by the launch vehicle and its systems.	
EM16	Conducted Susceptibility	Identify all frequency ranges for which the minimum conducted emission safety margin is not satisfied for the Host, the Payload and for the launch vehicle. Examine potential design changes and/or more extensive EMI/EMC testing that will improve and demonstrate safety margins and compatibility for these frequency ranges.	
EM17	DC Magnetics	Define the DC magnetic flux and dipole environment generated by the Host for the locations of the Payload's hardware.	
EM18	DC Magnetics	Define the DC magnetic flux environment generated by the Payload's hardware.	
EM19	DC Magnetics	Define the DC magnetic flux limitations that are imposed by the Host.	
EM20	DC Magnetics	Define the DC magnetic flux limitations that are imposed by the Payload.	
EM21	DC Magnetics	Confirm that sufficient margin exists between the Host and Payload for DC magnetic environments.	
EM22	Test	The Host and Payload should be tested in stowed and deployed conditions (as applicable) for all radiated emissions.	Lack of this type of testing has resulted in degraded performance on orbit.
EM23	PIM	Surfaces of Host and Payload should be examined to ensure that neither will introduce PIMs in the other's transmissions.	Preventive measures such as PIM blankets should be designed and provided space and clearance early in the project.

Fault Management

Fault Management is a coordinated effort, combining a fault tree with potential fault symptoms detected by state of health (SOH) telemetry (TLM) and transmitted to the ground station. The Failure Modes and Effects Analysis (FMEA) can be used to identify the candidate failure causes by working in reverse order to the unit or assembly level. Autonomous FSW is developed to correct and mitigate Host and Payload failure effects that are time-critical. Examples could be failure effects with short thermal time constants or when the Host is not visible to the ground station. When commanding the Host and Payload manually during specific mission phases, avoid commands on the prohibited list.

Table 16. Fault Management Checklist

Item	Topic	Consideration	Comments
FM1	Time Critical Failures	Verify that potential propagating failure modes needing timely correction to a Host "safe mode" have autonomous detection and mitigation.	The Host may have limited onboard SOH data available from the Payload, so Host action must be robust.
FM2	Not in LOS of Ground Station	Verify that potential propagating failure modes needing timely correction to a "safe mode" have autonomous detection and mitigation.	
FM3	Maintain High Performance Availability	Payloads requiring high performance availability may require autonomous detection and mitigation of failures.	
FM4	Ground Over-ride Capability	In the event of Payload processor failures, ground over-ride capability is needed.	
FM5	Selecting the Failure Detection Monitor	Based upon a combination of analysis and tests, select the failure monitor (e.g., current, voltage, temperature, watch-dog timer, etc.) that results in the most accurate and timely failure detection.	Payloads with multiple failure modes may require multiple monitors on Payload or Host side.
FM6	Encryption	Strategies should be developed to accommodate fault management for encrypted Host command links and any encrypted Payload commands.	
FM7	Fault Management Architecture	Payload faults that have criticality to Host may need mitigation on both Payload and Host sides of interface. Host faults that affect Payload should be understood and mutually mitigated.	Ownership of monitoring at Payload and Host levels must be understood at System level to avoid gaps.

Materials, Processes and Parts

Parts and materials used in the Host or Payload should be prevented from jeopardizing the other's mission. This is normally controlled through review of approved parts and material lists that provide essential characteristics for evaluation. If a sufficient parts or materials list is not available due to the use of COTS items, testing may be required to verify no harmful products evolve from the planned use.

Useful reference documents for this section include TOR-2006(8583)-5236 Rev B and EEE-INST-002. The SAE Q100 through Q200 series of automotive grade parts may be useful reference for lower class missions.

Table 17. Materials and Processes Checklist

Item	Topic	Consideration	Comments
MP1	Materials	The Payload or the Host should not use materials on a Prohibited Materials List without mutual approval.	Such materials include some metal that sublime and redeposit; platings that can grow whiskers and organic materials that outgas.
MP2	FOD	Foreign debris should be avoided.	FOD control programs at the unit level and system level should be implemented to decrease the chance of debris causing problems in test and on orbit. A line of sight analysis could be performed if FOD were considered a risk for the Host or Payload mission.
MP3	Processes	Develop a spacecraft integration flow chart and procedures defining all assembly steps, responsibilities and configurations.	Specify how the payload will be stored upon arrival, uncrated, installed, and tested. The procedure should detail the equipment, steps and resource involvement. Typical concerns are the need for possible nitrogen purges and the need to uncrate in clean rooms. End to end responsibilities and conflict resolution need to be defined.
MP4	Processes	Develop a test flow chart and procedure defining all steps in testing under the control of the host.	Specify what is to be measured and the equipment to be used by detailing the steps and resource involvement. Instances where the payload was tested in vacuum chambers that had just been refurbished and then outgassed, where incorrect temperature limits or power levels were applied during thermal tests or where power was applied to a data line must be avoided.
MP5	Processes	Payload integration and testing shall include a representative from the payload provider.	The responsibility of the representative is to guide the integrator through the intricacies of the payload and to insure no harm is done to the payload.
MP6	Processes	In-flight processes must take account of the host or payload vulnerabilities.	In-flight processes such as deployment of a payload, experiments within the host or payload or operation of solar arrays shall not adversely affect the other.
MP7	Processes	Manufacturing processes should follow proven flight standards.	The NASA 8739 series is typical for traditional manufacturing workmanship requirements.
MP8	Processes	Any new processes should be fully qualified and documented.	Qualification should be at the process level, and at the unit level.

Item	Topic	Consideration	Comments
MP9	PMP Review Board	A review board should be established for review and approval of all parts and materials.	The review board serves to identify issues early in the process before final parts and material lists are delivered. All participants should have a representative on the board.
MP10	Parts and Materials Lists	Parts and Materials lists are standard for the Host. Similar lists should be provided by the Payload for host review.	Part requirements for the Payload may be different from the Host, but all should be robust against the space environment.

Mechanical Integration and Test

Integration and test of any satellite can occasionally present issues that were not evident during the design phase. There are a few specific considerations that should be addressed with regard to hosted payloads to ensure that both Host and Payload are safely integrated and tested. For example, it may be important to consider de-integration of a hosted payload. De-integration and other considerations are listed in the checklist below.

Table 18. Mechanical Integration and Test Checklist

Item	Topic	Consideration	Comments
MI1	Test Orientation	Physical orientation of hosted payload during testing operations may require more analysis; 1G loading may also affect alignments. Will offloading be required?	May only be an issue if hosted payload was not designed for space. Can hosted payload be “tipped” or mounted on its side if necessary for testing?
MI2	Environmental Testing	Test notching, if permitted by LV provider, may be required solely because of the addition of the hosted payload.	
MI3	Grounding	Ensure that grounding of all individual components of hosted payload is adequate; one ground path between a hosted payload subassembly and the host is not sufficient.	All components need to be grounded individually, not grounded as one subassembly. May need additional ground beads, studs, copper tape, or straps.
MI4	Integration Accessibility	Consider mounting methods and accessibility for integration.	Externally mounted components (with reference to the host) may be easier to install.
MI5	De-Integration	Consider accessibility and removal methods and accessibility for hosted payload components.	Externally mounted components (with reference to the host) may be easier to remove if necessary.
MI6	Configuration Management	Keeping separate drawings and bills of materials for hosted components may assist in efficiency of integration.	Especially good if deintegration required.
MI7	Fit Checks	Hole Patterns, Flatness.	Common drill templates and early fit checks are necessary to reduce risk.
MI8	Axes Definitions	Definition of axes should be agreed upon during the design phase, but would be verified during alignments.	

Optics

Visible optics, optical communications devices, infrared, radar and other line-of-sight sensors are often contamination sensitive and require careful contamination control which is addressed in the previous checklist. They may have stability requirements as addressed in the ACS checklist and thermal distortion considerations that are related to thermal design.

Since optical payloads will be one of the most common types of hosted payloads, and since they do have additional considerations, they are included as a separate checklist.

Table 19. Optics Checklist

Item	Topic	Consideration	Comments
OP1	Field of View	Most sensors and optical equipment require an unobstructed field of view. This can be ensured using computer models such as Pro-E, but it is important to fully understand the geometry and origin of defined stay-out zones, including potentially unmodeled integration hardware such as blankets and fasteners.	
OP2	Field of View	Many sensors have susceptibility to glints, reflections or thermal radiation originating from regions outside their field of view. Again, these requirements must be fully understood and verified by computer models.	
OP3	Contamination	Aspects of contamination addressed in the Contamination checklist should be examined to determine whether they apply to the instrument in question. Optics line of sight to known contamination sources should be avoided.	
OP4	Pointing	Are thermal expansion coefficients between Host and Payload sufficiently similar that pointing errors are not introduced?	
OP5	Pointing	Will thermal distortions on Host surfaces cause the Payload to off-point excessively?	
OP8	LOS Knowledge	Optical payloads often require more accurate line-of-sight knowledge (LOSK) than other missions such as a communications satellite. The impact of adding a hosted optical payload to the spacecraft could be lessened if the host is amenable to modifying the LOSK sensor to satisfy hosted payload requirements.	
OP9	Pointing	Jitter requirements and performance should be analyzed to ensure the mission will perform as intended.	
OP10	Pointing	Optical axes and boresights, as well as the plan to ensure their alignment should be addressed early in the program.	

Power

Power may be supplied from the spacecraft bus, or may be downconverted in voltage and supplied on a dedicated line to the Payload. Since the payload will rely on the host as a DC power source, it is critical that detailed power interface requirements be established between the two entities. The purpose of these requirements is to ensure the safety and proper operation of both the host and the payload in all operating modes and mission phases. Good references for power systems include MIL-STD-1541 for EMC and SAE AS5698 for power systems in general.

Table 20. Power Checklist

Item	Topic	Consideration	Comments
PW1	Fusing	Assign whether the host or the payload will provide fusing protection on the payload's power inputs.	
PW2	Fusing	Determine the fuse size requirements to ensure reliable and quick response to short circuit conditions in the payload.	
PW3	Circuit Breakers	Determine the circuit breaker dynamic performance to ensure reliable and quick response to short circuit conditions in the payload.	Over current control within the payload must be compatible with the circuit breaker behavior.
PW4	Nominal Power Consumption	Determine the nominal and worst case power consumption requirements for all of the payload's operating modes and for all of the host's mission phases.	Uncertainty in power consumption early in Payload development phases should be managed by power budgets and margin Power feeds and cables should be appropriately sized.
PW5	Abnormal Power Consumption	Identify any potential payload failure modes that would result in abnormally high power consumption that is insufficient to blow the fuses.	The fuses should be sized such that any such shorts are tolerable to the Host. If not, the Host should be capable of manually or autonomously shutting down the Payload.
PW6	Leakage	Determine "Off" state power consumption limits for the payload consistent with all host mission phases.	The Host may consider implementing an isolation-capable power bus for the Payload.
PW7	In-rush Current	Determine in-rush current limits for the payload to apply to payload power up and step load changes for its operating modes.	Current limits should be determined by fuse/circuit breaker characteristics.
PW8	Out-rush Current	Determine out-rush current limits for the payload to apply to payload power down and step load changes for its operating modes.	Current limits should be determined by fuse/circuit breaker characteristics.
PW9	Hookup Current	Fusing, circuit breakers, relays and power supplies may require additional margin to ensure they can withstand powering a unit that has not been precharged by being connected to a power bus.	Charging input capacitors of a "cold" unit can cause a higher inrush current than would be typical of a turn-on transient.
PW10	Nominal Bus Voltage	Determine nominal bus voltage operating range for payload.	Voltage should be specified at the payload input connector.

Item	Topic	Consideration	Comments
PW11	Bus Voltage Fluctuations	Determine payload requirements for off-nominal power bus voltage fluctuations (under-voltage and over-voltage transients). Include operate through, survival and auto-shutdown requirements for these conditions.	
PW12	Bus Voltage Periodic and Random Deviation	Establish noise environment for normal and abnormal operation.	Could be satisfied by imposing EMI test standards.
PW13	Single Point Failures	The Payload's power circuitry should not have any unmitigated single point failures that would cause the Payload to either power on autonomously or fail to respond to an 'off' command from the host.	If the Payload design is fixed, then the Host may consider implementing an isolation-capable power bus for the Payload.
PW14	Telemetry	Establish payload requirements for power related telemetry, i.e., local bus voltage, DC current, on/off status, secondary power supply status, etc.	Used for fault detection/diagnosis and assessment of performance degradation.
PW15	Connectors	Positive power pins should have physical separation from ground pins and signal pins, i.e. they are not immediately adjacent to these other pin types.	Prevent secondary damage due to bent/damaged pins or foreign conductive particles.
PW16	Power Return	The power return design for the payload should minimize stray currents and ground loops on the host; e.g., electrically ground to a single point on the host.	Different Contractors and Payload providers may employ different unit/bus power return architectures: return to single point ground, chassis ground, etc.
PW17	Connector Contacts	Power sourcing contacts should be female.	Reduces chance of arcing if cable is disconnected when power is applied.
PW18	Voltage Drops	Voltage drops should be considered when providing power via cabling to a Payload.	Voltage should be specified at the interface to the payload, rather than at the power source.

Safety and Reliability

Safety and Reliability are critically important in hosted payload projects. While a typical commercial Host relies on heritage and established interfaces to ensure compatibility, attaching an independently developed Payload to an operational mission can give rise to both obvious and subtle conflicts. Though analyses do not have to go far into a circuit to be effective, analysis of all but the simplest interfaces must be deep to ensure integrity.

Table 21. Safety and Reliability Checklist

Item	Topic	Consideration	Comments
SR1	Probability of Success	Agree upon a set of reliability assumptions for host and payload if probabilities are required.	A uniform standard should be used for the analyses if it is required.
SR2	Interface Analysis	Develop Interface Reliability Block Diagram and Interface FMECA.	Payload should provide an analysis of potential failure modes and, if required, their probability.
SR3	Probability of Success	Generate interface reliability prediction for SPFs.	Failure probabilities of SPFs might need to be calculated.
SR4	Interface Analysis	Verify that interfaces are protected from potential propagating failures that could result in over-stress.	Fault protection needs to be in place for Host and Payload interfaces.
SR5	Failure Mitigation	Failure mitigation protection with “watch-dog” timers that sense “a loss of the clock” can be included in the timing system design architecture as required.	These have been used with units, such as focal plane arrays that experienced an increase in temperature with a loss of the clock.
SR6	Failure Mitigation	Baseplate temperature might be controlled by spacecraft sensors and switches.	If active switches are used, two series FET switches in series redundancy should be considered, to prevent a failed-on state which might overheat the Payload.
SR7	System Safety Program Plan	A system safety program plan should be developed in accordance with contract requirements.	Commercial programs may not require material and information beyond that mandated by the US Occupational Safety & Health Administration. International programs may have special requirements that should be reviewed and understood.
SR8	Failure Mitigation	The Payload DC/DC converters that convert the Host bus voltage to the secondary voltages needed for its electronics might have output over-voltage and current-limiting protection for mitigating potential fault propagating failures back to the Host.	Power cross-straps might be “diode-ored” for mitigating shorts of “upstream source outputs” and current-limit/over-voltage protection to avoid over-stressing “down-stream redundant loads or functions”.

Item	Topic	Consideration	Comments
SR9	Single Point Failure Prevention	Ensure adequate protection on power lines leading from the Host Power Bus to the Payload.	Fuses, resettable circuit breakers and current limiters might be used, though failure modes of these devices should be considered.
SR10	Single Point Failure Prevention	Product design guidelines, identifying minimum spacing between traces “in-plane and between planes,” should be followed to minimize the probability of shorts in multilayer boards or backplanes that serve as a common interconnect for prime and redundant functions.	Potential SPFs in multilayer boards or backplanes should be avoided by recommended separation of prime and redundant functions.
SR10	Special Attention Process Steps for Accepted Single Point Failure.	Consider use of a critical item control plan (CICP) for single point failure items, defining additional inspection and test steps for use during fabrication and test to reduce the likelihood of failure.	Examples of critical items are the Host primary power bus and single logical output of “2 of 3 majority voted” functions used in various power electronics circuitry for battery charge/discharge control and related functions.
SR11	Failure Mode Prevention	Be sure to check for subtle failure mechanisms such as breakdown of body diodes in MOSFETs.	These have resulted in unexpected “sneak paths.”
SR12	Single Point Failure Prevention	Consideration should be given to buffering of signal cross-straps through independent devices in separate packages to prevent single point failures.	This will avoid a single ground or power lead failure in disabling a multiple function package.
SR13	Single Point Failure Prevention	Power and ground lines should be analyzed to ensure loss of one connection will not result in loss of payload function.	Potential failure modes in the interconnecting harness, multilayer boards, and backplane assemblies should be evaluated.
SR14	Operations	Verify sufficiency of autonomous failure detection and correction is implemented for timely mitigation of failures in relation to the Payload.	This process has been used to address fault propagation leading to potential SPFs.
SR15	Critical Functions	Verify that fail-safe/redundant configurations are used for critical functions on the Host and Payload.	Examples are premature ordnance initiation and failed-on heaters.
SR16	Single Point Failure Prevention	Verify that prime and redundant cross-straps (e.g., telemetry & command, mission data, etc.) are isolated and buffered to prevent an interface failure.	Hardwire cross-straps of prime and redundancy signals are always potential SPFs.
SR17	Control of SPFs	Verify that known SPFs, such as the output of "2 of 3 majority-voted" logic have special attention plans to reduce the likelihood of a SPF.	Accepted SPFs that cannot be corrected by design rely on CICPs to reduce the likelihood of failure.
SR18	Single Point Failure Prevention	Verify that the product design requirements for trace separation between prime and redundant functions both in-plane and between planes are followed in common backplane and motherboard designs.	Minimum separation requirements are contained in the product design guidelines.
SR19	Control of SPFs	Verify that all accepted SPFs have a Critical Item Control Plan (CICP) identifying steps during the design, manufacturing and test to reduce the potential of failure.	Accepted SPFs that cannot be corrected by design rely on CICPs to reduce the likelihood of failure.

Item	Topic	Consideration	Comments
SR20	Failure Tolerance	Verify that there is a positive disconnect of primary power from the Host to prevent the loss of the Host Primary Power Bus and "smart shorts."	“Smart shorts” are not sufficient to “clear the fuse,” but continue to consume power.
SR21	Failure Tolerance	Verify that Host unintended commands are addressed.	If timely re-designs cannot be completed, unintended commands have been disabled with series relays to prevent uncontrolled commanding.

Structural and Mechanical Design

This checklist covers structural concerns including alignment and mass properties as well as issues related to mechanical design and analysis of the hosted payload. Launch and on-orbit environments are also considered here. It is important to note that structural and mechanical requirements for Payload units will vary by commercial Host spacecraft provider due to different architectures and launch vehicles. MIL-STD-1540 is a good reference for the types of test and analysis related to structural and mechanical aspects.

Table 22. Structural and Mechanical Design Checklist

Item	Topic	Consideration	Comments
SM1	Mounting Location	Available space is needed for all hosted payload components. Consider mounting all hosted payload components externally for easier access/installation.	If late addition, are all locations easily accessible without breaking configuration (minor adjustments may be okay)?
SM2	Support Structure	Adding a separate support structure to mount all hosted payload components can be beneficial for integration and testing.	A large solitary support structure may need a separate/delta CDR to finalize design as instrument matures.
SM3	De-integration	Consider mounting hosted payload externally or as one subassembly to assist with any de-integration to ensure host can fly on schedule.	If something goes wrong with the hosted payload during after integration, can all components/instrument be easily (relatively) removed so that host can fly on schedule?
SM4	Ballast Mass/Mass Simulator	Ballast mass may be required for integration or testing purposes, especially if the host will be tested individually. Mass simulators may be required for dynamics testing.	
SM5	Mounting large components/Physical FOV	Large structures on hosted payload need to clear all physical FOVs of host; if they do not, approval and/or additional analysis is required from host.	This includes static and all phases of deployment.

Item	Topic	Consideration	Comments
SM6	Grounding Locations	Ensure that grounding of all individual components of hosted payload is adequate; one ground path between a hosted payload subassembly and the host is not sufficient.	If hosted payload was not designed for space, grounding may not be adequate. All components need to be grounded individually, not grounded as one subassembly.
SM7	Host Component Adjustments	Do host components need to be moved to accommodate hosted payload rework?	Consider amount of time required for rework as well as lead time for additional support structures and waveguide.
SM8	Flatness	Ensure each new component or support structure has the flatness requirements needed for alignment or bond-line control during integration	
SM9	Stiffness	Host and hosted payload support structure may need to be stiffened to accommodate existing hosted payload modes.	
SM10	Qualification History	Hosted payload units may not have qualification history required for host customer; flight units may need to be subjected to protoflight vibration and shock testing.	
SM11	Analysis Levels	Requirements need to be flowed down to hosted payload as soon as possible for accurate analysis.	Environments for analysis and required margins of safety.
SM12	Coupled Loads Analysis	Coupled analysis may need to be developed to ensure host/hosted payload structural compatibility.	
SM13	Mass Measurement	Payload mass properties must be analytically derived to a very accurate level early in the Host design phase and then accurately measured prior to delivery to the Host.	Does the Payload provider possess analytical and test tools sufficient to meet Host accuracy/precision requirements?
SM14	Payload-Induced Dynamics	Payload launch locks or hold downs need to be released on-orbit.	Will release of Payload hold down mechanisms result in significant shock environment for Host?
SM15	Coefficients of Expansion	Check differential coefficients of expansion between the Payload and Host to ensure there is no excessive structural stress and no significant thermally induced pointing change.	
	Depressurization	Venting of structures needs to be considered.	

Thermal

Thermal design to accommodate a Payload is very much like system thermal design for a host mission. Conduction and radiation pathways must be provided to dissipate heat generated within the Payload, and heaters must be provided to keep the Payload within its operating and survival temperature ranges during all phases of the mission and during testing. The factory, shipping, and storage environments should be controlled and the environments defined so that any required protective measures for sensitive hosted payloads can be identified and provided.

Responsibility for thermal control should be well defined. The host may provide some or all of the thermal control or the hosted payload may need to provide autonomous thermal control. A cooperative effort where thermal control responsibilities are shared is typical. Usually, survival heaters will be powered by the host using host temperature sensors because initial safing protocol favors putting the payloads into a dormant or “safe” mode. Thermostatically controlled circuits should be used with caution, and mechanical thermostats are not considered to have high reliability when applied without redundancy.

Integral thermal designs may result in some unique concerns. Sometimes, the thermal design baseline and mounting interfaces may need to be completed very early in the design phase for heat pipe layout to be finalized and panels ordered in time. This may drive early definition of unit footprints, mounting feet, and heat conduction paths because of the need to install inserts into the panels.

Table 23. Thermal Checklist

Area	Topic	Consideration	Comments
TH1	Dissipation	Are there highly dissipating units in the hosted payload?	High dissipation may affect the panel temperatures defined as the thermal interface. This requires a coupled thermal analysis between the host and the hosted payload to assess heat rejection. Payloads with high dissipations require more power and create more significant thermal concerns making them less suitable for hosted payload opportunities.
TH2	Thermal Model	Does the hosted payload have significant thermal interactions with the Host?	Thermal models should be exchanged between the hosted payload provider and the Prime.
TH3	Mounting	What thermal dissipation capability is being provided with the mounting interface to the host?	Thermal mounting interfaces should be well defined between the host and Payload. Payloads that have minimal location restrictions are better candidates for hosted payload opportunities.
TH4	Heater Failure	Will a “stuck on” heater cause the Payload to overheat?	Redundant heater circuits are required to mitigate this risk. If heater failure is not mitigated with redundancy and overheating will affect the host, the ability to cut power off to and sacrifice the hosted payload will be required.
TH5	Active Cooling	Does the hosted payload require active thermal control devices?	Loops, cryo-coolers and other complex heat transfer mechanisms will require significant integration and more resources such as power and real estate.

Area	Topic	Consideration	Comments
TH6	Boundary Conditions	Has the host defined the boundary conditions for thermally integrating the host payload?	Radiative and conductive thermal boundary conditions should be well defined and managed by the Host.
TH7	Radiation	Does the host have sufficient radiator area allocated for the hosted payload and is there a strong thermal path to that radiator?	The location within the spacecraft and the amount of radiator area allocated to the host payload for heat rejection are critical factors for assessing host compatibility.
TH8	Reflections	Does the host or hosted payload have highly reflective surfaces?	Reflections from the payload and host should not provide thermal accentuation, such as “double-sun” conditions. Highly specular surfaces could cause directed light that interferes with mission functionality.
TH9	Programmable Heater Control	Is the hosted payload implementing programmable heater control?	Programmable heater control of the Payload represents a significant integration effort with the host. Can heater parameters be updated once on-orbit?
TH10	Thermal Backload	Are there payload appendages in the field of view of thermal radiators?	Host appendages in or near the Payload radiator may result in undesired IR backloading. Similarly, Payload appendages may create backloading concerns for Host radiators
TH11	Non-operating Survival	The host payload should assume that power may be cut to their system for extended periods of inactivity, e.g., during launch, orbit raising, in-orbit test, and contingency operations.	Survival heaters must be sized to accommodate worst-case non-operating periods. Control of these survival heaters is usually a host responsibility.
TH12	Host Payload Thermal Safing	The Payload may fail or complete its mission prior to the end of the host mission.	The thermal environment in this situation should be verified to not cause physical degradation of materials within the Payload.

Appendix B. Hypothetical Payload and Payload Interface Equipment FMECA and Propagating Failure Lists

Payload Interface Equipment FMECA

Item No.	Block No.	Function	Failure Modes	Failure Causes	Effects on Payload	Effects on Spacecraft	Observable Symptoms	Compensating Provisions	Crit.	Recommendations or Remarks
1	1	**Power Control** Low Voltage Converter Qty = 2	Fault at the power input connection to the power supply	Broken or failed connection, mechanical failure. Open circuit or short of main bus input to ground.	Loss of all low voltage output power to payload.	None	Payload status telemetry		1S	A fuse is provided upstream to prevent loss or degradation of the main power bus.
2	1		No output voltage or current.	Random part failure, failed solder connection	Reduced power available to payload	None	Payload status telemetry. Performance degradation of payload may be detectable.		1S	
3	1		Short at the output of the power supply	FOD or electrical short to ground at the output.	Short to ground at payload input.	None	Payload status telemetry. Performance degradation of payload may be detectable.		1S	
4	2	**Additional functions and equipment**	…	…	…	…	…	…	…	…

Payload Interface Potential Propagating Failure Item List

Subsystem	Item	Quantity	Failure Mode	Failure Effect	Payload Failure Effect	Crit.
Payload Support Equipment	Power Supply	2	Loss of power	Reduction in available power from 800 Watts to 400 Watts	Requires Evaluation by Payload	1S
Payload Support Equipment	Power Hub	1	Open wire	Loss of power to one module	Loss of one module. Further evaluation to be done by Payload	1S
Payload Support Equipment	Fuse Block	5 Fuses	Open fuse	Loss of power to one module	Loss of one module. Further evaluation to be done by Payload	1S
Payload Support Equipment	Power Switch	5	Open contact or failure to switch on.	Loss of power to one module	Loss of one module. Further evaluation to be done by Payload	1S

Hypothetical Payload FMECA

Item No.	Block No.	Function	Failure Modes	Failure Causes	Effects on Payload	Effects propagating to spacecraft	Observable Symptoms	Compensating Provisions	Crit.	Recommendations or Remarks
1	1	**DC to DC power converter**	Open at the power input connection to the power converter	Open circuit or trace on the power line.	Loss of all voltages to parts of the payload powered by this converter. Reduced redundancy.	None.	Payload status telemetry		1R	
2	1		Short of Input Capacitors	Random part failure, failed solder connection	Loss of power from this converter	Short of input power to return	Payload status telemetry.		1S	Fuses, relays or fold-back converter might reduce effects on the spacecraft.
3	1		Fault at the power output connection of the power supply	Broken or failed connection, mechanical failure.	Reduced power available to Payload	None.	Payload status telemetry. Performance degradation of Payload may be detectable.		1S	
4	2	**Additional functions and equipment**	…	…	…	…	…	…	…	…

Payload Potential Propagating Failure Item List

Subsystem	Item	Quantity	Failure Mode	Failure Effect	Host Failure Effect	Crit.
Payload	DC Converter	2	Input short to ground	Short of power input to return	Requires evaluation by Host	1S
Payload	Telemetry Point	4	Open wire	Open wire	Causes wire to not have connection to ground. Further evaluation to be done by Host	1S
Payload	Telemetry Point	4	Short to ground or return	High-side of telemetry is connected to ground.	Requires evaluation by Host	1S
Payload	1553 connection	2	…	…	...	…

For these examples, the following criticality codes are used. These typically vary somewhat by manufacturer, but are relatively similar across industry.

Criticality Categories

Criticality Categories	Assembly/Equipment Level	Subsystem Level	Spacecraft Level
1	Failure mode results in risk of loss or degradation of other equipment (risk of failure propagation) or constitutes a safety hazard.	Failure mode results in risk of loss or degradation of other functional subsystems (risk of failure propagation) or constitutes a safety hazard.	Failure mode results in complete loss of the spacecraft and all of its missions (referring to specified requirements) or constitutes a safety hazard.
2	Failure mode results in complete loss of operational capability of the equipment under consideration.	Failure mode results in complete loss of operational capability of the subsystems under consideration.	Failure mode results in partial loss or severe degradation of mission.
3	Failure mode results in severe degradation of operational capability of equipment under consideration.	Failure mode results in severe degradation of operational capability of subsystems under consideration.	Failure mode results in only minor or negligible degradation of mission.
4	Failure mode results in only minor or negligible degradation of equipment under consideration.	Failure mode results in only minor or negligible degradation of subsystems under consideration.	(No category 4 for the spacecraft.)

The criticality designations are further classified into those that result from single-point failure items (S) and those resulting from failure of redundant items (R).

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